TP. 4792E

# OPERATIONAL DYNAMICS

## MV ARCTIC

## SCIENTIFIC PROGRAM

## INTERIM REPORT

Prepared for

Transportation Development Centre

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17. Abstract

This report presents an interim review of the MV Arctic Scientific Program from its inception in January 1977 to the commencement of the Detailed Data Analysis Phase in July 1983.

The report addresses all aspects of the program from the objectives, the instrumentation system fitted on the ship, the data collection activity with a review in depth of the database, the preliminary findings leading to the requirements and strategy of the final phase of detailed data analysis.

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| 15. Remarques additionnelles | 16. Agent de projet — CDT |
| Rapport intérimaire menant à un rapport final en 1984 sur les résultats du programme d'évaluation scientifique du M.V. Arctic. | M. Brenckmann |

17. Résumé

Ce rapport passe en revue le programme d'évaluation scientifique du M.V. Arctic depuis le début, en janvier 1977, jusqu'à l'amorce de la phase "Analyse détaillée des données", en juillet 1983.

Il aborde tous les aspects du programme: objectifs, instrumentation et système de saisie des données mis en oeuvre, collecte des données, etc. Il fait aussi un examen approfondi de la base de données avant de présenter des conclusions préliminaires quant aux objectifs de la phase qui doit débuter ainsi qu'en ce qui concerne la stratégie à adopter.

| 18. Mots-clés | 19. Diffusion |
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| Instrumentation, saisie des données, déglaçage, navire de cote arctique, navigations maritimes, structures navales, appareils propulsifs, performances de navires. | Le CDT dispose d'un nombre limité d'exemplaires. |

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# 1. INTRODUCTION

This report presents an interim review of the mv Arctic Scientific Program from its inception in January 1977 to the commencement of the Detailed Data Analysis Phase in July 1983.

The report addresses all aspects of the program from the objectives, the instrumentation system fitted on the ship, the data collection activity with a review in depth of the database, the preliminary findings leading to the requirements and strategy of the final phase of detailed data analysis.

## 2. BACKGROUND TO MV ARCTIC PROGRAM

The development of reliable technology and sound operational practices for arctic shipping is fundamental to the safe and economic exploitation of oil and mineral resources in the north. In furtherance of these aims and recognising the special difficulties and risks surrounding arctic marine operations, the Government of Canada has taken the following two important steps in recent years.

- In 1972, proclaimed the Canadian Arctic Waters Pollution Prevention Act (CAWPPA) supported by Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR) to provide standards, criteria and guidelines for the admission of ships to the Arctic based upon the best knowledge available at that time.

- In 1975, agreed to participate jointly with a group of Canadian shipowners in the construction and operation of the mv Arctic, a CASPPR Class 2 icebreaking cargo vessel.

Federal responsibility for each of the above is vested with the Ministry of Transport. In the latter case, a condition of government participation was that the technical and commercial experience derived from the mv Arctic venture would be made available to all sectors of the Canadian marine industry having shipping interests connected with arctic transportation. To that end, the Ministry of Transport assigned the responsibility for recording and publicizing the technical components of this project to the Transportation Development Centre. TDC initiated this program of instrumentation system development, data collection and analysis, following Treasury Board approval in 1977. The program has the following six objectives.

## OBJECTIVES

1. To evaluate the structural strength standards and other design criteria assumed to be necessary in the Arctic Shipping Pollution Prevention Regulations, for a vessel of Class II, and to offer a quantitative and qualitative appraisal of these standards for other Classes of icebreaking cargo vessels envisaged by these Regulations

2. To evaluate the restraints on seasonal operation periods and zones currently established in the regulations for a vessel of Arctic Class II

3. To develop improved or more appropriate forms of navigation and communications equipment for Arctic Class vessels with particular respect to ice reconnaissance and forecasting; position finding devices and collision avoidance systems

4. To establish a co-relation between the performance of the tank-tested model of the vessel in ice with actual vessel under Arctic operational conditions, and to establish its icebreaking efficiency under actual and diverse operational conditions of weather and ice intensity.

5. To establish the degree of effectiveness, in the continuous ice-breaking mode, of special features incorporated into the initial design of the proposed vessel such as an air bubbling system to reduce the frictional effects of broken ice and a ducted propeller feature

6. To provide an instructional base upon which the expertise of ice navigation and commercial ship operation in Arctic waters may be further developed and dispensed

**It is immediately evident from the above that there are three important and interrelated thrusts embodied in these objectives, namely, the evaluation and improvement of the design, performance and safe operation of icebreaking ships. Actual field experience is the only reliable basis for evaluating the soundness of current codes of arctic marine practice and the mv Arctic Scientific Program was designed and implemented with these essential purposes in mind.**

## 3. STATUS OF THE MV ARCTIC PROGRAM

The objectives of the mv Arctic program are described in the previous section of this report and the plan of implementatation consists of three main phases as follows,

Phase 1 - Provision of instrumentation aboard the vessel to sense and record the requisite scientific data.

Phase 2 - The collection and annual reporting of scientific data whilst the vessel was engaged in commercial arctic voyages.

Phase 3 - Detailed analysis of the collected data to gain a quantitative measure of the vessel's performance in ice, leading to the development and trial of more advanced instrumentation systems.

These three program phases and their outputs are shown diagramatically in Attachment 3.1. The status with respect to each phase is as follows,

Phase 1. The contract for this phase was placed in 1977 and was completed with the commissioning of the instrumentation system in June 1979. The design and installation was completed by mid 1978 when the ship was delivered and followed immediately by structural load calibration. The first arctic season, July to November 1978, was used for familiarisation and debugging the system. Repairs to hull damage delayed final acceptance until June 1979. The main events of this phase are tabulated in Attachment 3.2. A detailed description of the instrumentation system fitted in this phase is provided in Section 4 of this report.

Phase 2. The instrumentation system has been operated by a number of contractors over three full arctic seasons from July to November for the years 1979, 1980 and 1981 and has accumulated ship operating data on a total of twelve round voyages between Europe and the arctic loading terminal at Nanisivik in Strathcona Sound. Ship performance has been monitored as deemed necessary throughout the ice-transiting period and at other times to give comparative open-water data.

In addition to the above original program, full advantage has also been taken of other opportunities to conduct four sets of dedicated trials. The purpose of these trials was to examine special hull-ice inter-relationships under controlled conditions in uniform and non-uniform ice regimes. Complete reports on these activities have been published and distributed to interested parties. The principal events covered in phase 2 are described in Attachment 3.2 in chronological order. A more detailed review of the data collection phase is provided in section 5 of this report.

Throughout the data collection phase, constant attention has been directed towards ensuring the appropriateness of the data being gathered in terms of meeting the program objectives. A complementary task has been the need to identify and record all factors which in any way affected the quality of the recorded data. To these ends, the various system operators have done the following,

- Ascertained and certified that the system was fully operational at the commencement of each season and capable of generating reliable data.

- Performed calibration and verification exercises and ensured adequate maintenance of the system throughout the data collection period.

- Selected data sampling patterns to suit the operator's recording aims in pursuance of the underlying program objectives.

A detailed review of the database collected and the potential for using it to address the program objectives is provided in section 6 of this report.

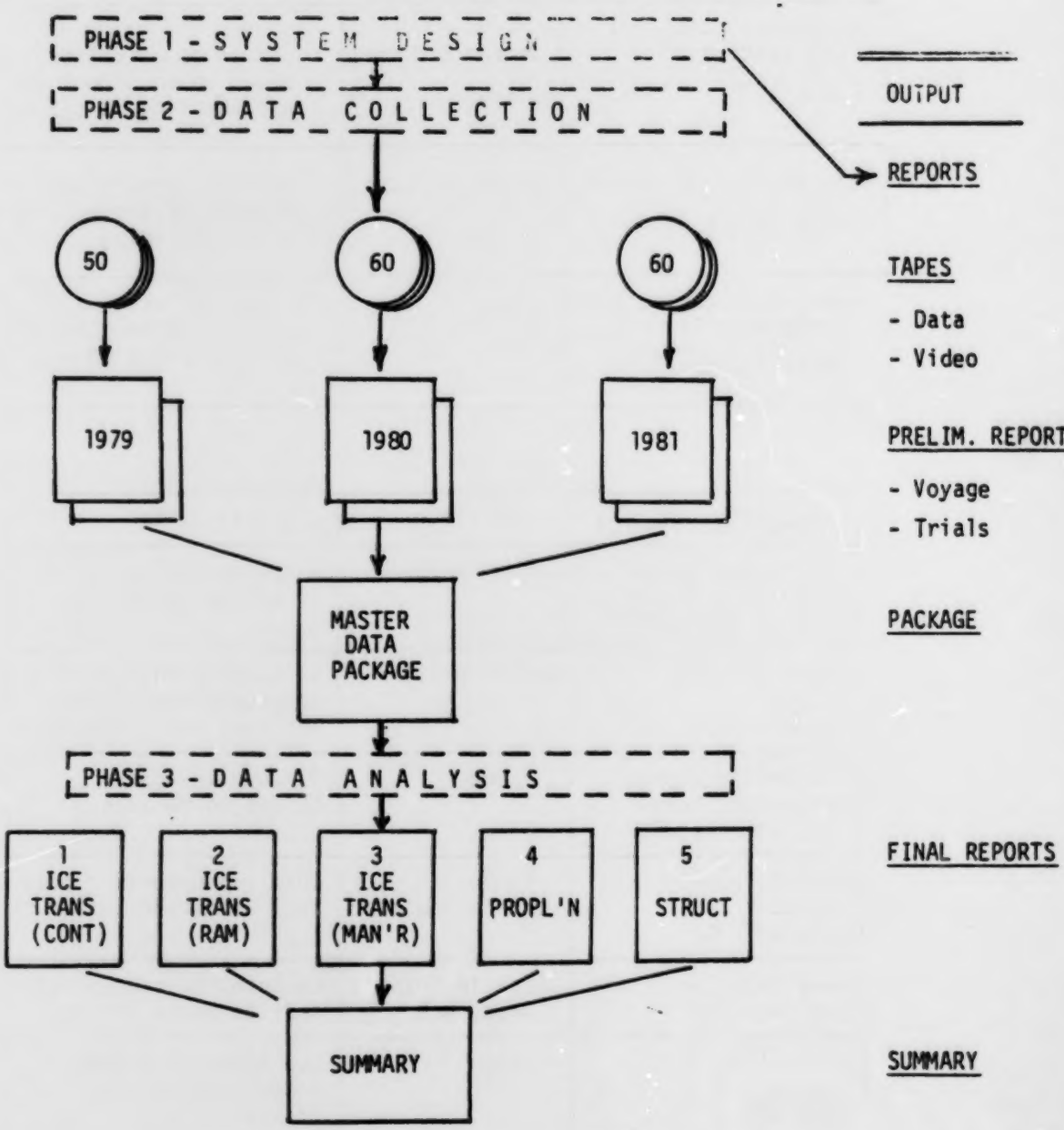
Phase 3. This final phase of the program commenced in 1982 with the preparation of a Master Data Package which describes and summarises all the data collected during the acquisition phase. This package together with a complete inventory of datatapes, videotapes and reports was a necessary pre-requisite to the detailed data analysis activities and dissemination of the results which form the objective of the final phase.

The process by which the databank will be reduced, analysed, interpreted and disseminated is of particular importance since no previous program has been so far reaching nor able to create such an extensive bank of real-time operating data for an icebreaking cargo vessel engaged on her commercial missions throughout the arctic navigation period permitted for a vessel of her class. The results of this phase will greatly facilitate the process of evaluating the various criteria underlying the development and operation of such vessels which is implicit in the mv Arctic program.

The Master Plan for the detailed data analysis phase of the program and its schedule of implementation is described in section 7 of this report.

ATTACHMENT 3.1

# MV ARCTIC PROGRAM PHASES



| PHASE 1 Events | Contractors | Description |
|---|---|---|
| Design & instal System 1977 - June 1978 | German & Milne<br>Fenco | 255 Channel computer-ised sensor system with 169 sensors allocated to structural strains on finite element array |
| Structural Load Calibration July 1978 | German & Milne<br>Fenco | Strain gauge calibration based on 50 ton load applications to structure |
| Familiarization Period 1978 Arctic Season | German & Milne | General running and de-bugging of system during arctic voyaging |
| System Calibration & Acceptance Tests April - June 1979 | German & Milne | Final calibration of the system and development of conversion equations |

| PHASE 2 Events | Contractor | Description |
|---|---|---|
| 1st Arctic Voyage Monitoring Season July to Nov. 1979 | German & Milne | 4 round voyages - Europe to Nanisivik |
| Saguenay River Trials* January 1980 | German & Milne | Straight-line runs & manoeuvering trials in level ice conditions |
| 2nd Arctic Voyage Monitoring Season July to Nov. 1980 | Fenco | 3 round voyages Europe to Nanisivik |
| Baffin Island Trials * October 1980 | Fenco<br>Lloyd's Register | Ship performance trials<br>Hull vibration trials |
| Lake Melville Trials* February 1981 | Melville Shipp'g<br>Fenco, NRC | Exploratory commercial service probe |
| Admiralty Inlet Trials * July 1981 | Fenco | Ice transiting and ridge penetration trials |
| 3rd Arctic Voyage Monitoring Season<br>Part 1 July-Sept 1981<br>Part 2 Sept-Nov. 1981 | <br>Fenco<br>Arctic Canada | Europe to Nanisivik<br>2-1/2 round voyages<br>2-1/2 round voyages |

* Dedicated Trial periods, extra to original program.

## 4. VESSEL AND SYSTEM DESCRIPTION

The mv Arctic is a 28,000 dwt bulk carrier designed by Camat Ltd and built by Port Weller Drydock in 1978 in accordance with Class 2 standards of CASPPR - the Canadian Arctic Shipping Pollution Prevention Regulations. The vessel is shown in Attachment 4.1, and her principal particulars are provided in Attachment 4.2.

In respect of the Program Objectives provided previously in section 2 of this report, an instrumentation system was designed by German & Milne Inc. and installed in the vessel to monitor and record selected parameters with respect to structure, propulsion, steering, motions and the related environmental conditions. The general layout of the data acquisition system is given in Attachment 4.3 together with a block diagram in Attachment 4.4. The system is controlled by a Rolm 1603A mini-computer and the configuration of the system permits the use of 256 data channels of which 212 were originally used. The sensor allocation is given in Attachment 4.5 from which it will be seen that strain gauges form the majority of the sensor system - 169 of the 212 original sensors. Most of the strain gauges are located on the starboard bow area and originally from frame 178 forward but later this array was extended back to frame 168. The final strain gauge array for the starboard bow is shown in Attachment 4.6,.

Strain gauge location analysis was performed by Fenco Consultants Ltd and was based on the finite element method of structural analysis. By means of this approach, the total ice load on the structure can be determined at any instant by the strain pattern appearing at that moment. A full scale calibration of the structural response to known applied loads was performed to provide information for conversion of strain to load.

The data acquisition system has been designed for automatic operation and to be run by personnel with a minimum of training. It is designed to;

(a) collect sensor data and store it on tape;

(b) permit limited viewing and analysis of the data via hardcopy printout while it is being collected.

The applications software comprises two basic programs, i.e., an acquisition program and a playback program.

The operator is free to select the sampling pattern to suit any particular requirement. For example, as in monitoring, he may be interested in one channel only, while in the case of actual ice trials he may wish to record all available data. He may also select the rate at which any channel is sampled and the mode of sampling. Once data gathering is started, the sampling of sensors is continuous. However, the recording of data to tape is optional. The pre-sampling plan comprises;

Pattern - Any sensor or combination of sensors.

Rate - Seven sampling rates are available provided the total number of samples/second does not exceed 1765. Available rates may be applied to any sensor, bearing in mind the total rate limitation, as follows;

| | Prior to Oct '80 | After Oct '80 |
|---|---|---|
| Rate 1 - | 1 sample/10 sec | 1 sample/10 sec |
| Rate 2 - | 1 sample/sec | 1 sample/sec |
| Rate 3 - | 10 samples/sec | 10 samples/sec |
| Rate 4 - | 40 samples/sec | 50 samples/sec |
| Rate 5 - | 100 samples/sec | 100 samples/sec |
| Rate 6 - | 250 samples/sec | 500 samples/sec |
| Rate 7 - | 1000 samples/sec | 1000 samples/sec |

Mode - Samples of the instantaneous values may be taken (real). Since it is possible in this mode to miss a peak, a second alternative mode using a peak holding circuit can be used.

Alarm - The operator can preset high and low values which when exceeded will be recognised by the computer and will activate recording.

The operator also has the choice of setting the system to operate in either continuous recording or a standby mode. If continuous recording mode is selected, all data collected is written to tape. This may be useful for calibration and testing but, in general, will record masses of uninteresting data. If the standby option has been selected any or all sensors may be assigned alarm limits to distinguish interesting values from uninteresting ones.

As long as no sensor exceeds its alarm limit no data is recorded on tape, although the sensors are being sampled continuously. When any sensor exceeds its alarm limit, recording is started and continues for a pre-selected interval (30 seconds, for example) after which the program reverts again to the standby mode. One second's worth of data is recorded to tape every hour to provide static load and other information.

Until the operator halts data gathering, the sampling and recording of data takes precedence over other functions. Nevertheless, it is possible to verify operation of the system via two printout options which operate concurrently with data gathering,

(a) Monitoring

Any sensor may be selected for continuous printout and a value is typed periodically at a rate dependent on printer speed limitations. This is useful for checking a sensor which may be expected to vary over a period of seconds. It is not capable of reflecting changes occuring at faster rates due to printer speed limitations.

(b) Logging

In the absence of monitoring, logging printout is automatically produced. One value for every sensor is typed at an interval selected by the operator (every 2 hours, for example). This is useful as a permanent record that the system is working, and also as a check on the proper functioning of the sensors. All values exceeding their alarm limits are flagged on the printout and a careful check can be made of readings on sensors that are not alarmed to ensure that they are reasonable.

The playback program provides a limited capability for reviewing recorded data on board. The tape may be searched by alarm limit, or by date and time, to locate an area of interest. When this is located, the operator may proceed in one of three modes;

(a) Monitoring mode prints every Nth value (N selected by the operator) of one selected sensor.

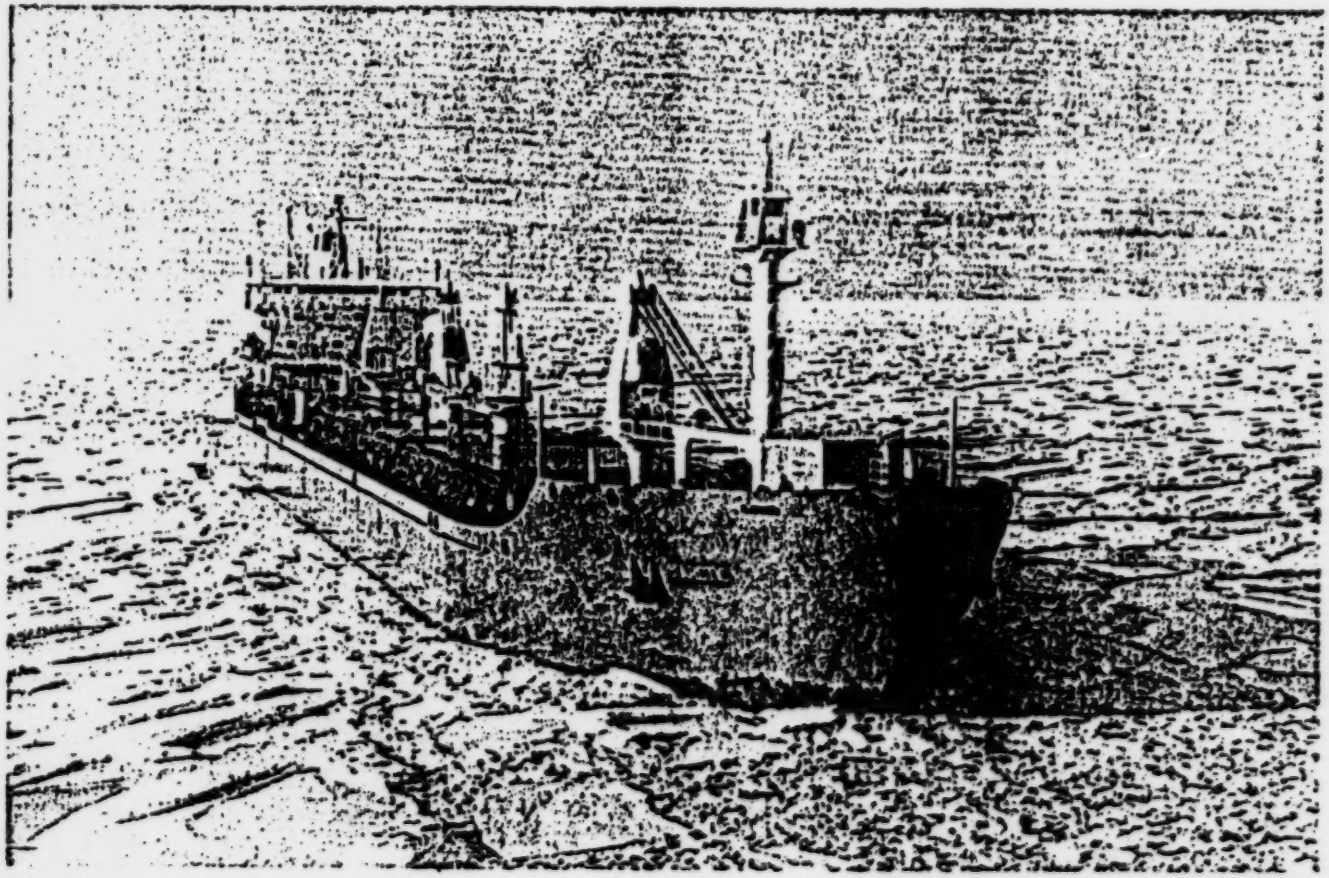
(b) Dump mode prints every value recorded. This mode will be used only for de-bugging and system verification.

(c) Statistics mode, no printout occurs as the tape is read. Statistics are accumulated and then printed when all records on the tape have been read.

Although limited statistical data can be provided under (a) aboard the vessel, any detailed analysis of the accumulated data must be carried out ashore on a main-frame computer.

In addition to the digital datarecording system described above, the installation also included a closed circuit TV system for video recording. The system comprised a TV camera mounted on the forward mast and capable of horizontal panning from right ahead to about 160 degrees on either side with about 45 degrees vertical panning. The TV pictures were recorded to tape on a Panasonic video recorder which could be played back at normal or fast speed for viewing through a CRT display unit. The video records can be time synchronised with the data tapes for comparison purposes.

Against this description of the instrumentation system, the next section of the report reviews the system operation and data collected since 1978.



—photo by Bill Rhodes, M.P.I. Productions Ltd.

M.V. ARCTIC

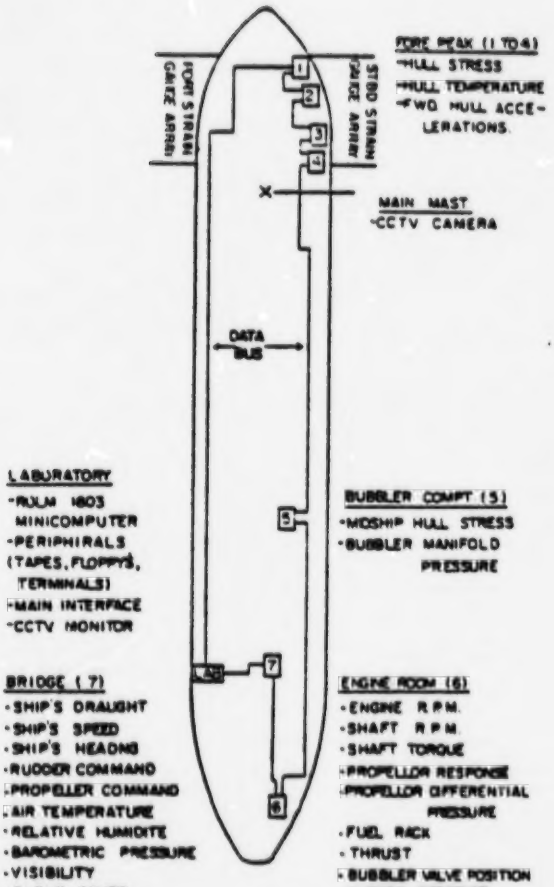
ATTACHMENT 4.1

**ATTACHMENT 4.2**

## M.V. ARCTIC - LEADING PARTICULARS

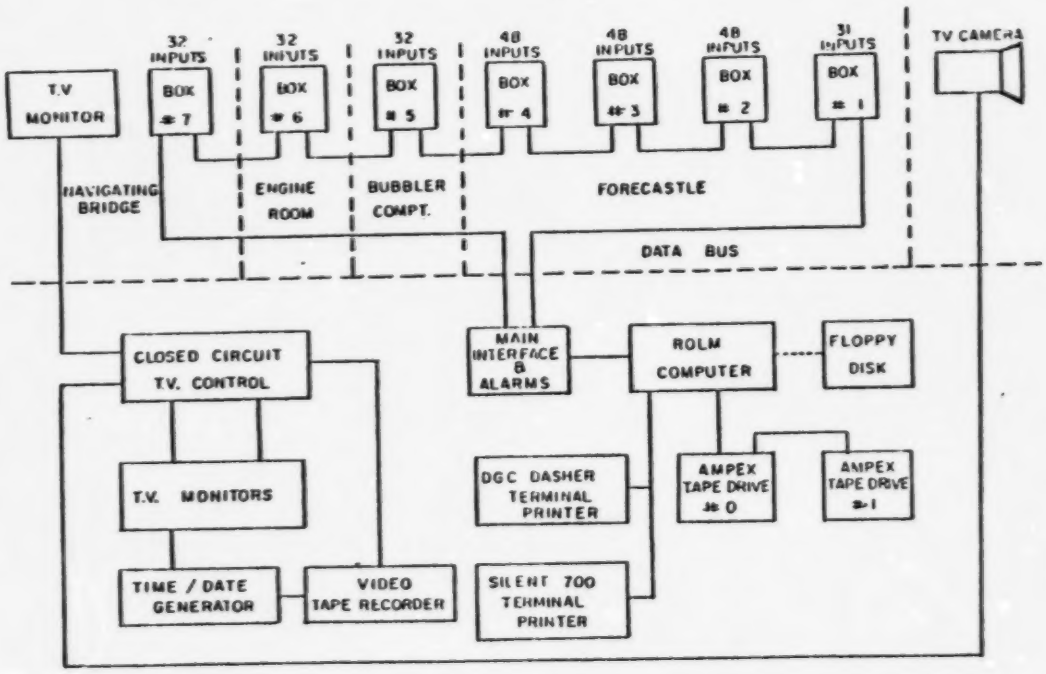
| | |
|---|---|
| Length Overall | 209.55 metres |
| Length Between Perpendiculars | 196.60 m. |
| Moulded Draught | 22.86 m. |
| Moulded Depth | 15.24 m. |
| Moulded Breadth | 10.97 m. |
| Summer Draught | 10.82 m. |
| Block Coefficient | 0.753 |
| Prismatic Coefficient | 0.761 |
| Light Ship | 9,276.1 tonnes |
| Displacement at 10.82 m. draught | 37,724.1 t. |
| Dead Weight at 10.82 m. draught | 28,448.0 t. |
| Cargo Capacity | 36,490.8 cubic metres |
| Propulsion Machinery - MAN Diesel | 11,014 kilowatts |
| Generators | 900 kw x 3 |
| Complement | 40 |
| Speed on Trials | 15.5 knots |
| Cruising Range | 14,000 Nautical miles |

ATTACHMENT 4.3




NOTE – JUNCTION BOX NUMBERS IN PARENTHESES

LAYOUT DIAGRAM OF DATA ACQUISITION SYSTEM



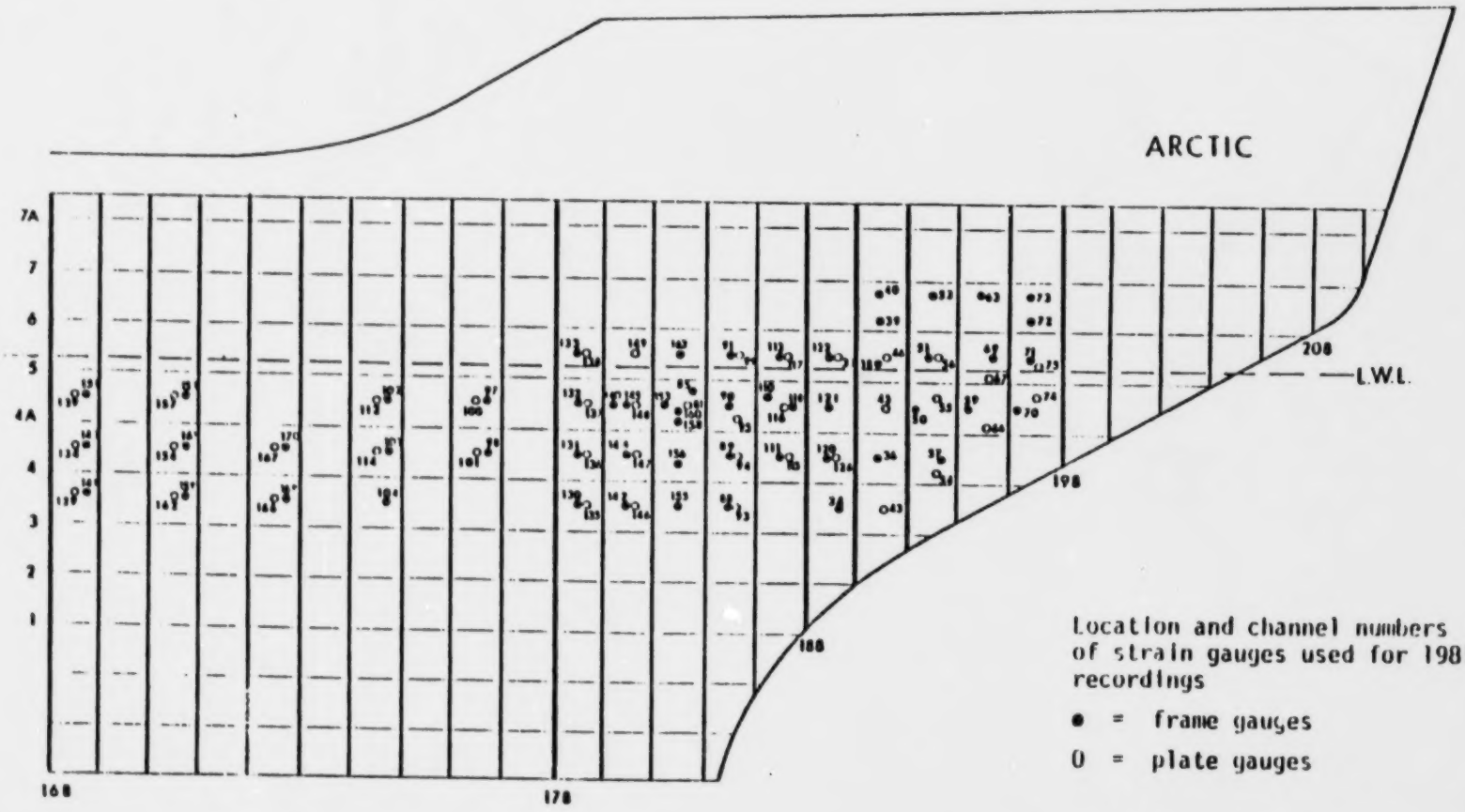

BLOCK DIAGRAM OF DATA COLLECTION SYSTEM

ATTACHMENT 4.4

INSTRUMENTATION

| Measured Parameters | Derived Parameters | Type of Sensor | Range | Number of Channels |
|---|---|---|---|---|
| **1. HULL STRUCTURE** | | | | |
| Structural Strains Starboard Bow | Ice Loads<br>Impact Counts<br>Pressures | Strain Gauge Ailtech Type SG 129 | ±2000 Microstrains | 139 |
| Structural Strains Port Bow | Ice Loads<br>Impact Counts<br>Pressures | Strain Gauge Ailtech Type SG 129 | ±2000 Microstrains | 20 |
| Structural Strains Field Ice Pressure Midship Hull | Ice Loads<br>Impact Counts<br>Field Ice Pressure | Strain Gauge Ailtech Type SG 129 | ±2000 Microstrains | 10 |
| Hull Temperature Above Water Line | Temperature Gradient | Thermistors Fenwal Electric Type GB 32P2 | -20° to +50° C | 2 |
| Hull Temperature Below Water Line | Temperature Gradient | Thermistors Fenwal Electric Type GB 32P2 | -20° to +50° C | 2 |
| **2. PROPULSION SYSTEM** | | | | |
| Shaft Thrust | Total Thrust | Renk Thrust Meter Type-RCIK-3 | ±120 MegaPons | 1 |
| Fuel Rack Position | Fuel Consumption Power | Follow-up Potentiometer | 0-100% of full travel | 1 |
| Propeller Pitch Response | Pitch Change Resistance | Follow-up Potentiometer | 16° - Astern<br>22° - Ahead | 1 |
| Propeller Pitch OD Box-Differential Pressure | Propeller Spingle Torque | Pressure Transducer SELABS Type SE 21/V | 0 - 14 Mega-Pascal | 1 |
| Shaft Torque | Shaft Horsepower | S/G Bridge & Telemetry Torque Meter | 0 - 0.8 Mega-Newton-metres | 1 |
| Engine RPM | Brake Horsepower | Ship Engine Instrumentation | RPM 0 - 600 | 1 |
| Shaft RPM | Shaft Horsepower | Ships Shaft Tachometer | RPM 0 - 200 | 1 |
| Propeller Pitch Command | - | Follow-up Potentiometer | ±10 Ahead<br>-10 Astern | 1 |
| **3. AUXILIARY SYSTEM** | | | | |
| Air Pressure Bubbler Compressor Starboard | Air Volume Flow | Pressure Transducer Entran EPS-1032-50 | 0-35 Kilo-Pascal | 1 |
| Air Pressure Bubbler Compressor Port | Air Volume Flow | Pressure Transducer Entran EPS-1032-50 | 0-35 Kilo-Pascal | 1 |
| Bubbler Valve Status | Bubbler Mode | Decoding Relays-From Modem of Valve Status | ON-OFF | 3 |
| Rudder Command | - | Follow-up Potentiometer | 37.5° Port<br>37.5° Stbd. | 1 |

| Desired Measurement | Derived Parameter | Type of Sensor | Range | Number of Channels |
|---|---|---|---|---|
| **4. SHIP PERFORMANCE** | | | | |
| Accelerations Heave, Surge, Sway - Fwd. | Ship Motions Ice forces | Accelerometers Entran Devices Inc. EGC-240-107 | ±10G | 3 |
| Accelerations Heave, Surge Sway - Aft | Ship Motions Ice forces | Accelerometers Entran Devices Inc. EGC-240-107 | ±10G | 3 |
| Rudder Angle Response | Rudder Change Resistance | Follow-up Potentiometer | 37.5° Port 37.5° Stbd. | 1 |
| Steering Gear Differential Pressure | Rudder Stock Torque | Pressure Transducer SELABS Type SE 21/V | 0 - 35 Mega-Pascal | 1 |
| Ships Speed | Resistance | Doppler Log-Sperry Type SRD-301 12 Bit Digital Number | 0-50 Knots | 1 |
| Ships Head | Turning Rate | Gyro Compass Type 37 Sine & Cosine of Heading | 0-360° | 2 |
| Pitch | Ship Motions | Vertical Gyro-Humphry Inc. Model VM02-0127-1 Pitch Axis | 0-40 Degrees Head & Stern | 1 |
| Roll | Ship Motions | Vertical Gyro-Humphry Inc. Model VM02-0127-1 Roll Axis | 0-40 Degrees Port & Starboard | 1 |
| Draught (Fwd) | Displacement Wetted Surface | Manual Operation Decade Switch | 7-12 Metres 1/2 Metre Steps | 1 |
| Draught (Aft) | Displacement Wetted Surface | Manual Operation Decade Switch | 7-12 Metres 1/2 Metre Steps | 1 |
| **5. ENVIRONMENTAL CONDITIONS** | | | | |
| Cloud Cover | - | Manually Operated Decade Switch | 0-10 Tenths Cover | 1 |
| Ice Cover | - | Manually Operated Decade Switch | 0-10 Tenths Cover | 1 |
| Barometric Pressure | - | Manually Operated Decade Switches | 0-100 Kilo-Pascals | 3 |
| Air Temperature | - | Manually Operated Bourns Knobpot | 0-100° C | 1 |
| Relative Humidity | - | Manually Operated Bourns Knobpot | 0-100% | 1 |
| Wind Speed | Wind force and moment | Anemometer Tachometer-Meteorological Instrumentation | 0-100 Knots | 1 |
| Wind Direction | Wind force and moment | Wind Vane Synchro. Meteorological Instrumentation | 0-360° to Ship's Head | 1 |
| Visibility | - | Manually Operated Decade Switch | 0-10 Nautical Miles | 1 |




Location and channel numbers of strain gauges used for 1981 recordings

● = frame gauges

0 = plate gauges

ATTACHMENT 4.6

## 5. REVIEW OF THE DATA ACQUISITION PHASE

### 5.1 Overview of data collected

The instrumentation system was installed aboard the mv Arctic when the ship was delivered in May 1978. Thereafter followed a period of testing, familiarisation and calibration until June 1979 when the ship was commissioned. During the ensuing three year period 1979 - 1981, the vessel operated twelve commercial round voyages between Europe and Nanisivik from July to November in the arctic shipping season when the ship's performance was monitored by the instrumentation system. The schedules of these voyages are given in the attachments as follows;

| | | |
|---|---|---|
| 1979 Season | 4 round voyages | Attachment 5.1 |
| 1980 Season | 3 round voyages | Attachment 5.2 |
| 1981 Season | 5 round voyages | Attachment 5.3 |

The period spent in ice-affected waters varied from season to season as shown in Attachment 5.4 and overall amounted to about 29% of the vessel's seatime on these voyages. In addition to voyage monitoring, data was collected during four dedicated trials which took place as follows;

| | |
|---|---|
| January 1980 | Saguenay River Trials |
| October 1980 | Baffin Island Trials |
| February 1981 | Lake Melville Trials |
| July 1981 | Admiralty Inlet Trials |

Throughout the three year period some 180 datatapes and 24 videotapes were collected as listed below

| | | |
|---|---|---|
| 1979 Season | 39 | datatapes |
| 1980 Season | 21 | " " |
| 1981 Season | 54 | " " |
| Saguenay | 9 | " " |
| Baffin | 22 | " " |
| L. Melville | 17 | " " |
| Admiralty | 5 | " " |
| Total (originals) | 167 | " " |
| L. Mel (reformats) | 13 | " " |
| Grand total | 180 | datatapes |

Datatape content averages 5 to 6 million pieces of data so that the total database approaches one billion pieces of data, which is clearly a substantial analysis task. The data recording time totals about 266 hours, the breakdown of which is shown in the following table according to the transiting conditions and the transiting mode,

RECORDING HOURS

| MODE \ CHANNEL | BROKEN | OLD | NEW | OPEN WATER |
|---|---|---|---|---|
| CONTINUOUS | 38 | 2 | 109 | 29 |
| RAMMING | 3 | 1 | 42 | -- |
| ASTERN | 13 | 1 | 2 | 5 |
| TURNING | -- | - | 15 | 6 |

Reports have been submitted by the various system operators for each season and dedicated trial. The main purpose of these reports was to catalogue the data collected and provide some very preliminary analyses and findings relating to the particular records which each operator had collected. A selection of these analyses is now provided.

## 5.2 Samples of preliminary analyses

A selection of the preliminary analyses taken from the various system operators' reports have been extracted and grouped below under the five main performance titles for which detailed studies will eventually be conducted.

a) Ice-Transiting Performance (continuous mode)

Icebreaking performance curves are given in Attachments 5.5 and 5.6 for continuous mode operation. From these and other records, it would appear that the vessel has an ultimate continuous mode capability approaching four feet ice thickness although designed to Class 2 which is taken as equivalent to two feet ice thickness. The bubbler appears to give some advantages in this mode.

b) Ice-Transiting Performance (ramming mode)

Icebreaking performance curves are given in Attachments 5.7 and 5.8 for ramming mode operation. Early indications are that ramming speed of advance can be optimised, in this instance by using a 4 knot ice ramming speed. Again the bubbler appears to improve performance. In the various ridge penetration tests which have been conducted, such as the one shown, the number of rams have varied from 1 to 12 to penetrate ridges having ostensibly similar dimensions. Accordingly, the true relationship between ridge parameters and penetration capability has to be established for the mv Arctic.

c) Structural Performance

The findings taken from four preliminary analyses related to structural performance are given in Attachments 5.9 to 5.12,. The pattern of plate and frame strains arrived at for the short period analysed showed only a small percentage occurance of strains above 300 microstrains. One a few days later, however, one of the records showed a strain approaching 1800 microstrains resulting in a permanent structural deformation. It has been noticed that the individual operator's conclusions reached in the three seasons showed substantially different biases towards the upper level of recorded strain range. Although these preliminary conclusions seem much at variance with each other, possibly influenced by each analyst's viewpoint and choice of data, it is also possible that they could be accurately reflecting seasonal differences largely attributable to varying ice conditions.

It appears from the attachments that there is some relationship between speed and strain, even at slow speeds. Striking ice floes at high speeds have certainly produced yield-level strains. There also appears to be significantly higher strains associated with ramming than with continuous mode icebreaking.

d) Propulsive Performance

The principal interest into propulsive performance is the effect on torque and thrust of ice ingestion into the propellor, one example of which is given in Attachment 5.13. Whilst no damage to the propellor or power train has been observed during the data acquisition period, the extent to which ice effects have brought the propulsion system near to overload conditions has yet to be determined.

e) Manoeuvering Performance

Preliminary findings with respect to steering gear loads and turning manoeuvers are given in Attachments 5.14 and 5.15,. In the matter of turning circles, the bubbler has been found to assist in some cases and not in others. Heeling has also been found to be of advantage in one instance. Three examples are given in the following table where R/L represents the turning circle radius to length of ship ratio, all taken from the Lake Melville trials,

| Rudder Angle | Ice Thickness | R/L | Condition |
|---|---|---|---|
| $22^{o}$ port | 2.6' | 13.4 | Bubbler off/no heel |
| $20^{o}$ port | 2.6' | 13.0 | Bubbler on /no heel |
| $22^{o}$ stbd | 2.6' | 9.4 | Bubbler on/$5^{o}$heel(s) |

No comprehensive conclusions can be reached from these results as they relate only to partial turns and with some differences of rudder angle.

d) Ship Motions

Ship motions are sub-divided into two categories, namely,

- Rigid body (pitch,roll,yaw,heave,surge,sway.)
- Flexing (bending,springing,vibration,)

Examples of each category are given from the preliminary analyses in Attachments 5.16 and 5.17. In the case of the rigid body motions, a relationship can be seen between roll, pitch and speed in ridge ramming. In the case of springing, synchronism at a primary mode frequency of about 1 Hz can be seen between the heave accelerometers and the hull girder strain gauges.

## 5.3 Overall preliminary impressions

The reports submitted by the system operators contain a variety of preliminary findings such as the foregoing but are not conclusive. Two general impressions seem to be evident among these findings which are as follows,

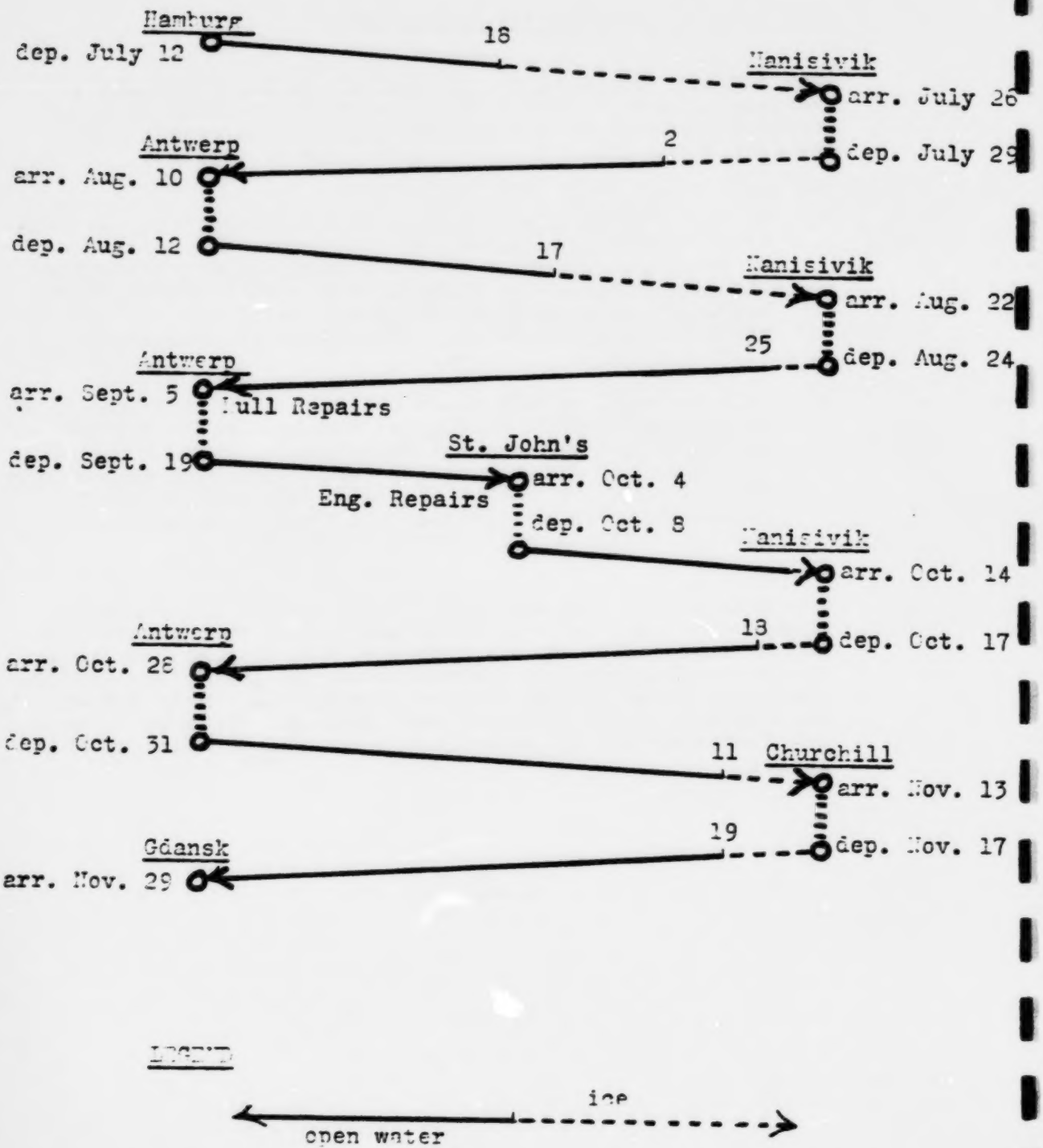
a) Performance of the mv Arctic in ice-transiting has been established in a variety of conditions and appears to be generally superior to the design targets associated with an Arctic Class 2 level. The effectiveness of the bubbler system, the special epoxy paint coating and the propellor nozzle all contributed in this result.

b) Critical hull stress cases during icebreaking appear to be more related to multi-year ice encounters ( which are of as yet unknown characteristics) than to ice-transiting in first year ice (which has been extensively documented). Ice encounters at higher ship speeds in broken channels and partial ice conditions also give rise to critical hull stress conditions.

The preliminary analyses have proved useful in providing examples of various analytical approaches to the reduction and interpretation of the database, but they are not able or intended to provide comprehensive answers to the various questions posed by the program objectives. These answers are the aim of the Detailed Data Analysis Phase which has now commenced and is described in the next section of this report.

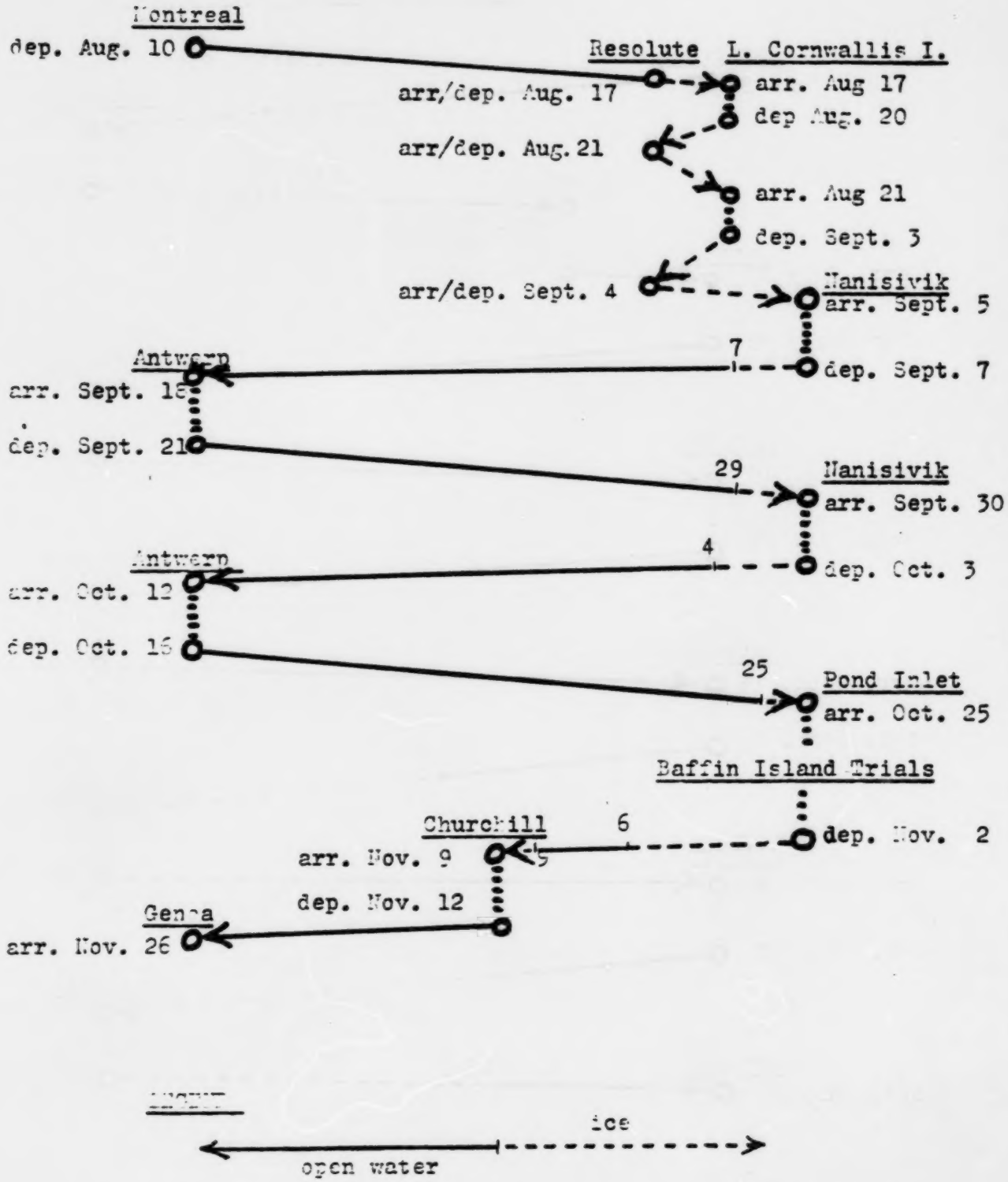
**ATTACHMENT 5.1**

1979 ARCTIC SEASON - M.V. ARCTIC



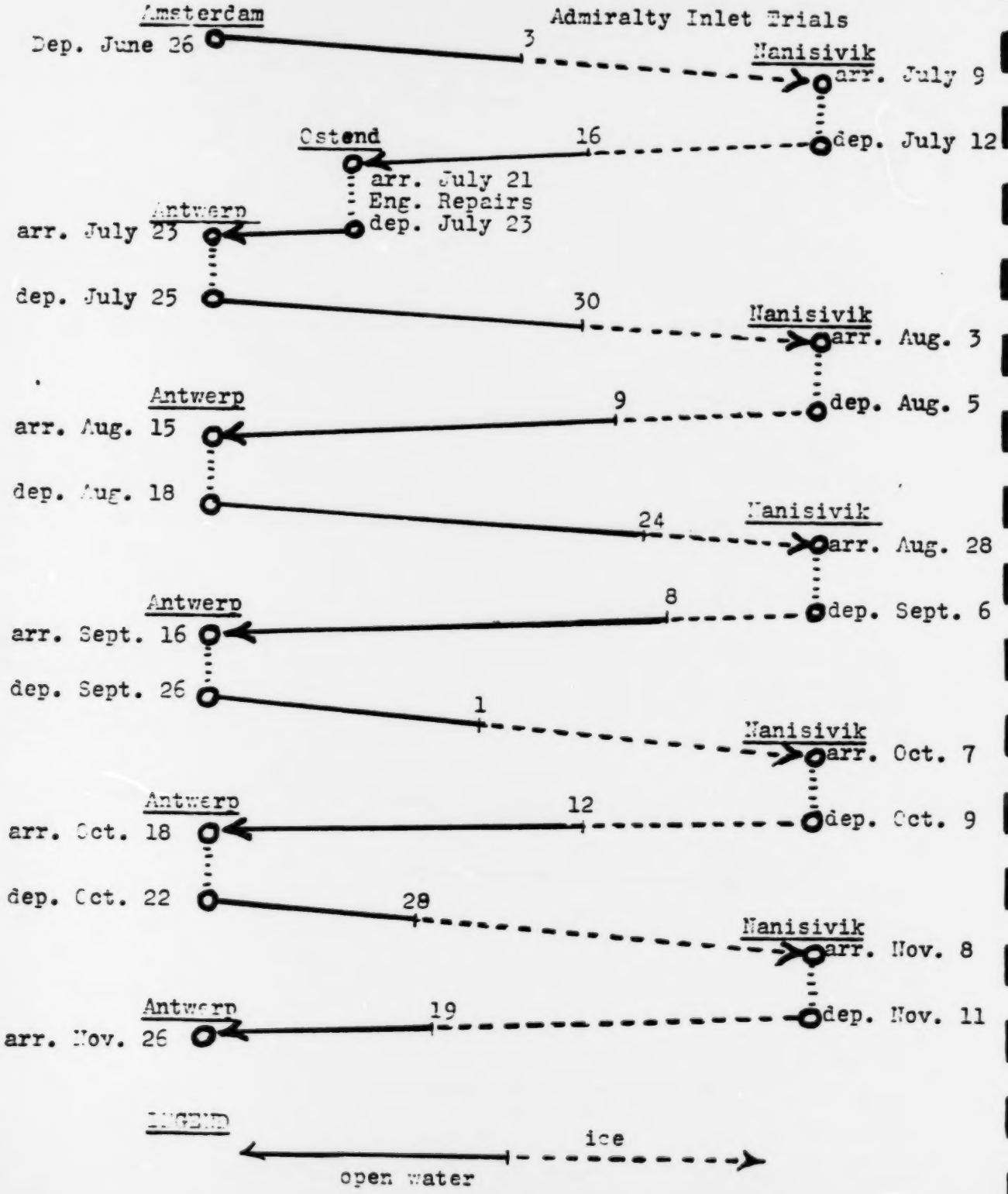
**ATTACHMENT 5.2**

## 1980 ARCTIC SEASON - M.V. ARCTIC



**ATTACHMENT 5.3**

## 1981 ARCTIC SEASON - M.V. ARCTIC

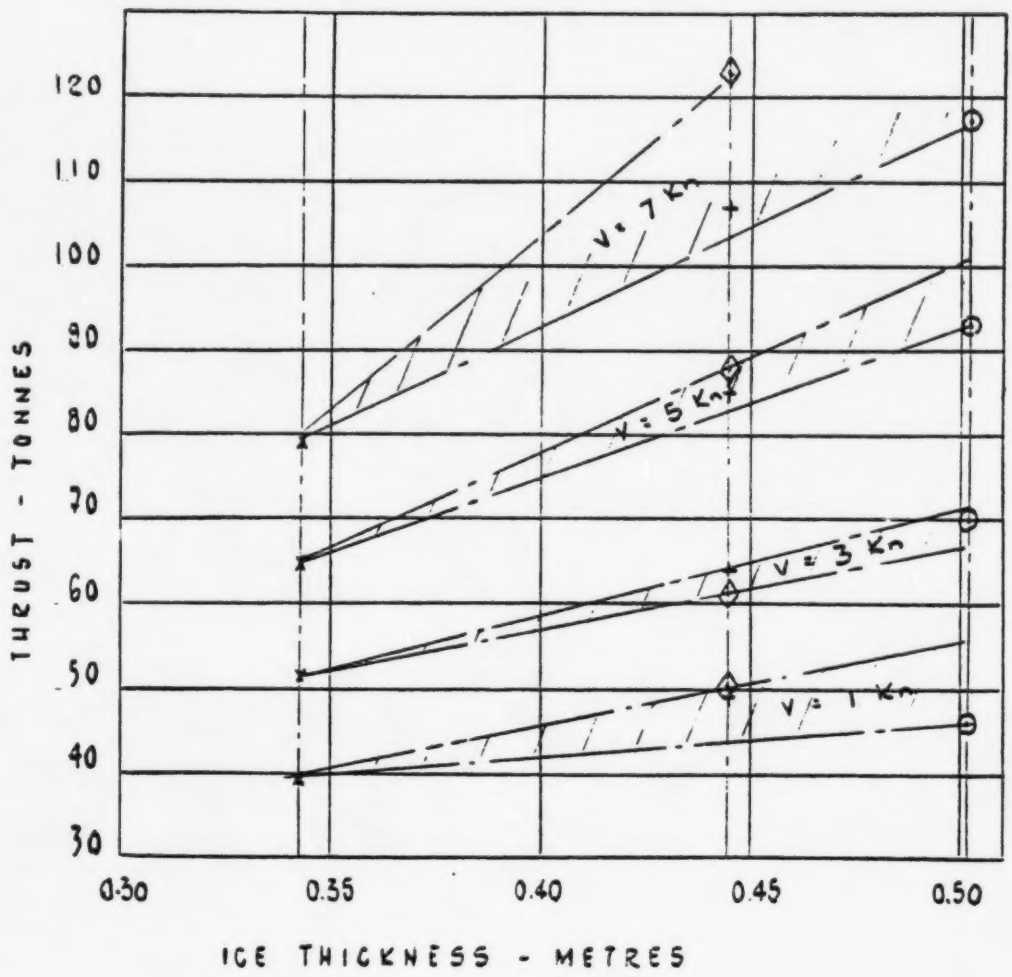


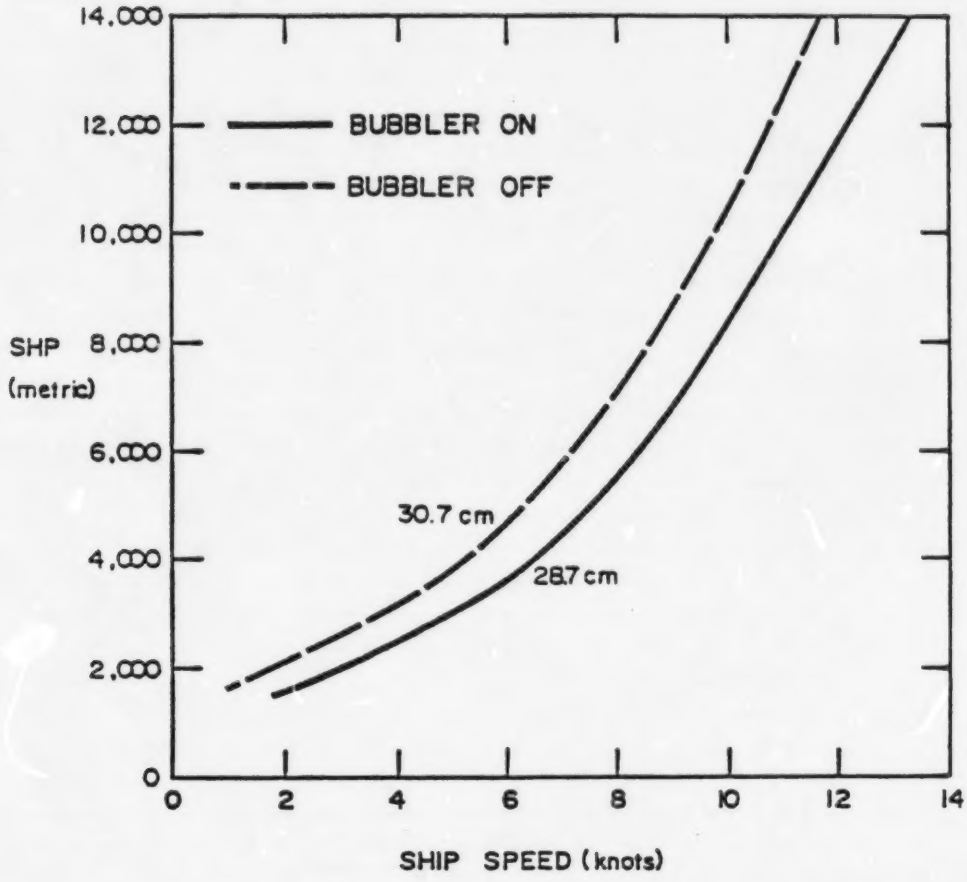
## VOYAGE SUMMARIES

| | Arctic Season (Days) | | | |
|---|---|---|---|---|
| Passage Time | 1979 | 1980 | 1981 | Total |
| Ice affected | 19 | 14 | 58 | 91 |
| Open Water | 86 | 56 | 59 | 201 |
| Total Seatime | 105 | 70 | 117 | 292 |
| Total Porttime | 35 | 33 | 39 | 107 |
| Total Season | 140 | 103 | 156 | 399 |
| Ice % of Seatime | 18% | 20% | 49% | 29% |

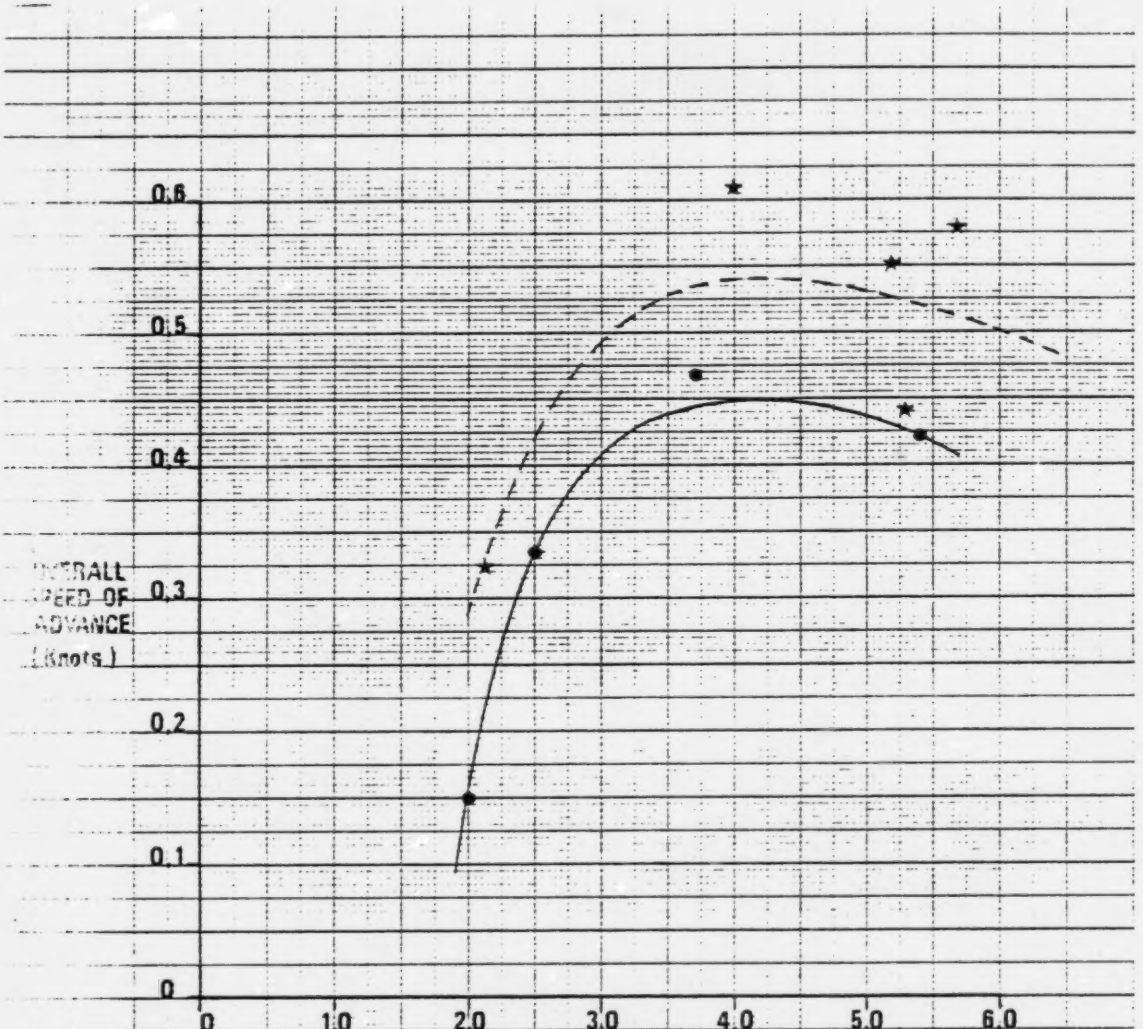
ATTACHMENT 5.5

# ICEBREAKING PERFORMANCE CURVES



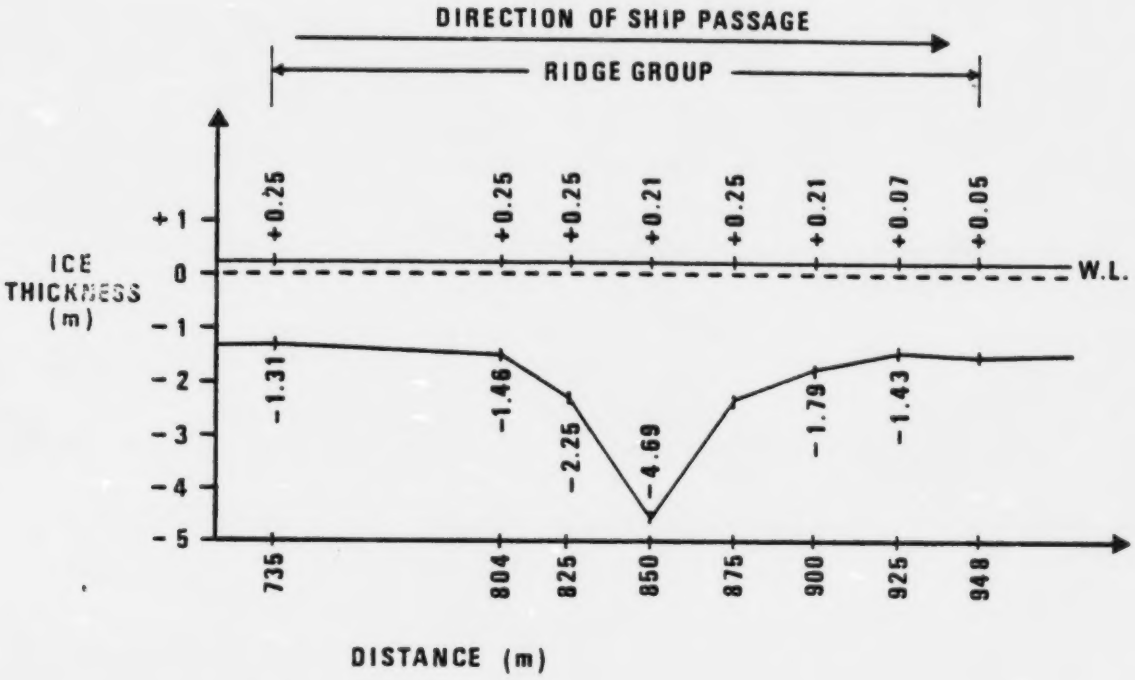


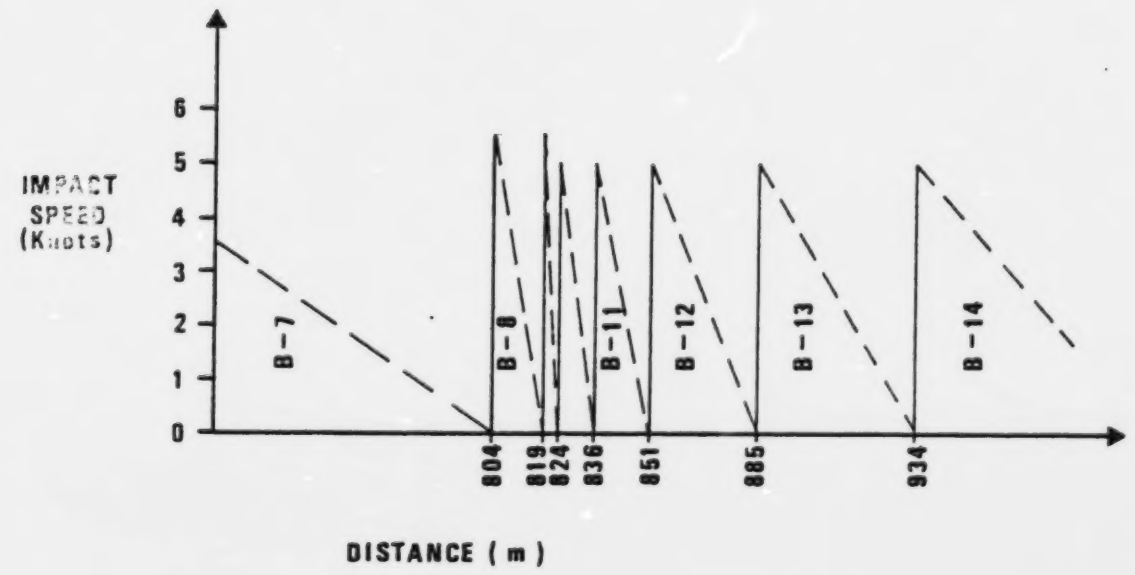

Power/Speed Plots for the M.V. Arctic
in level ice, with and without the bubbler.




SPEED OF ADVANCE – IMPACT SPEED
( In Level Ice )

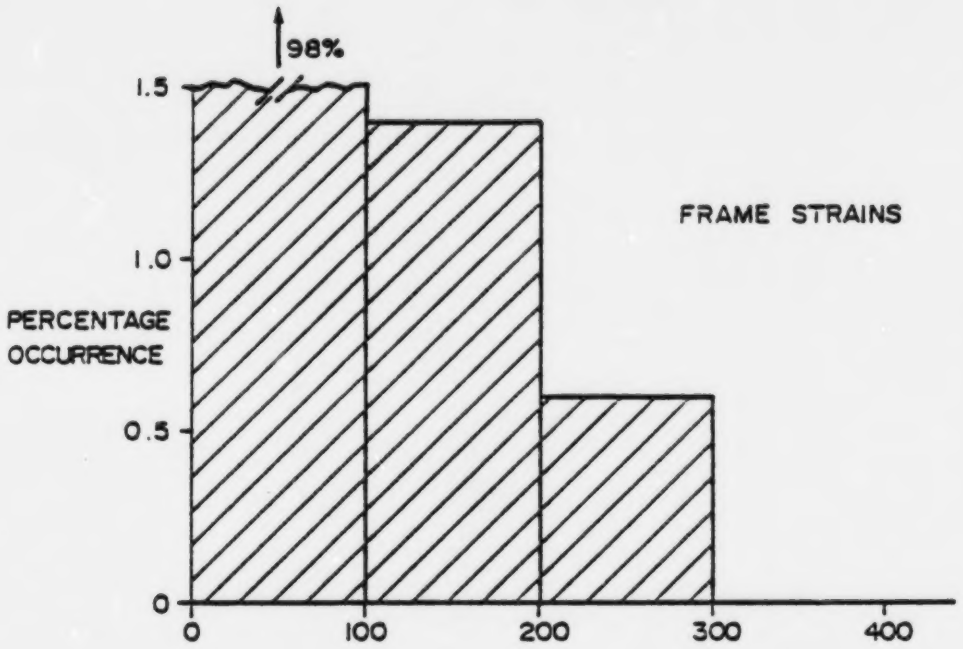
ATTACHMENT 5.8

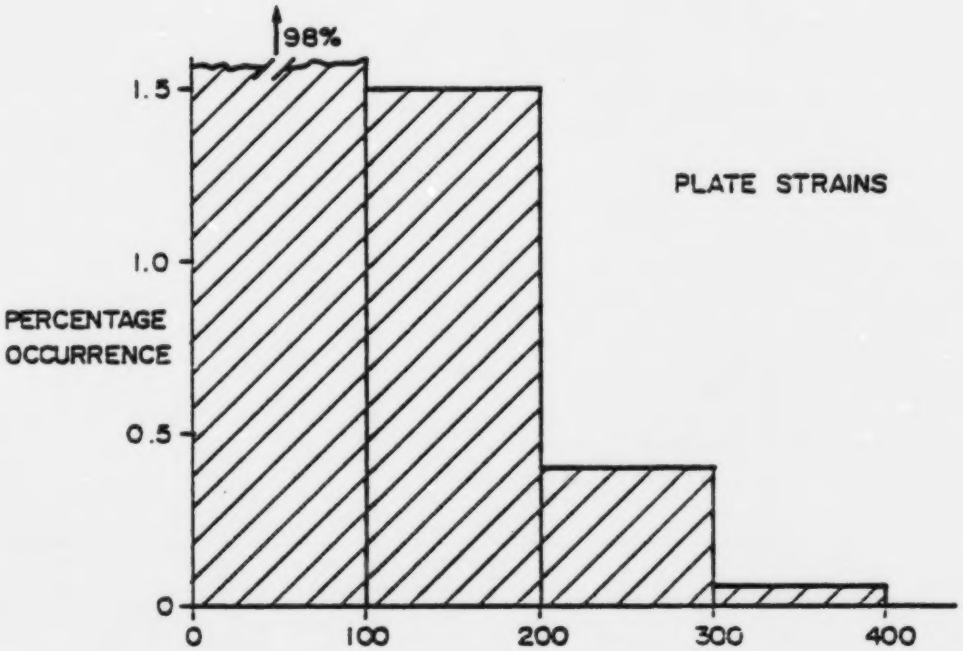



SHIP'S PERFORMANCE WHEN RAMMING A RIDGE

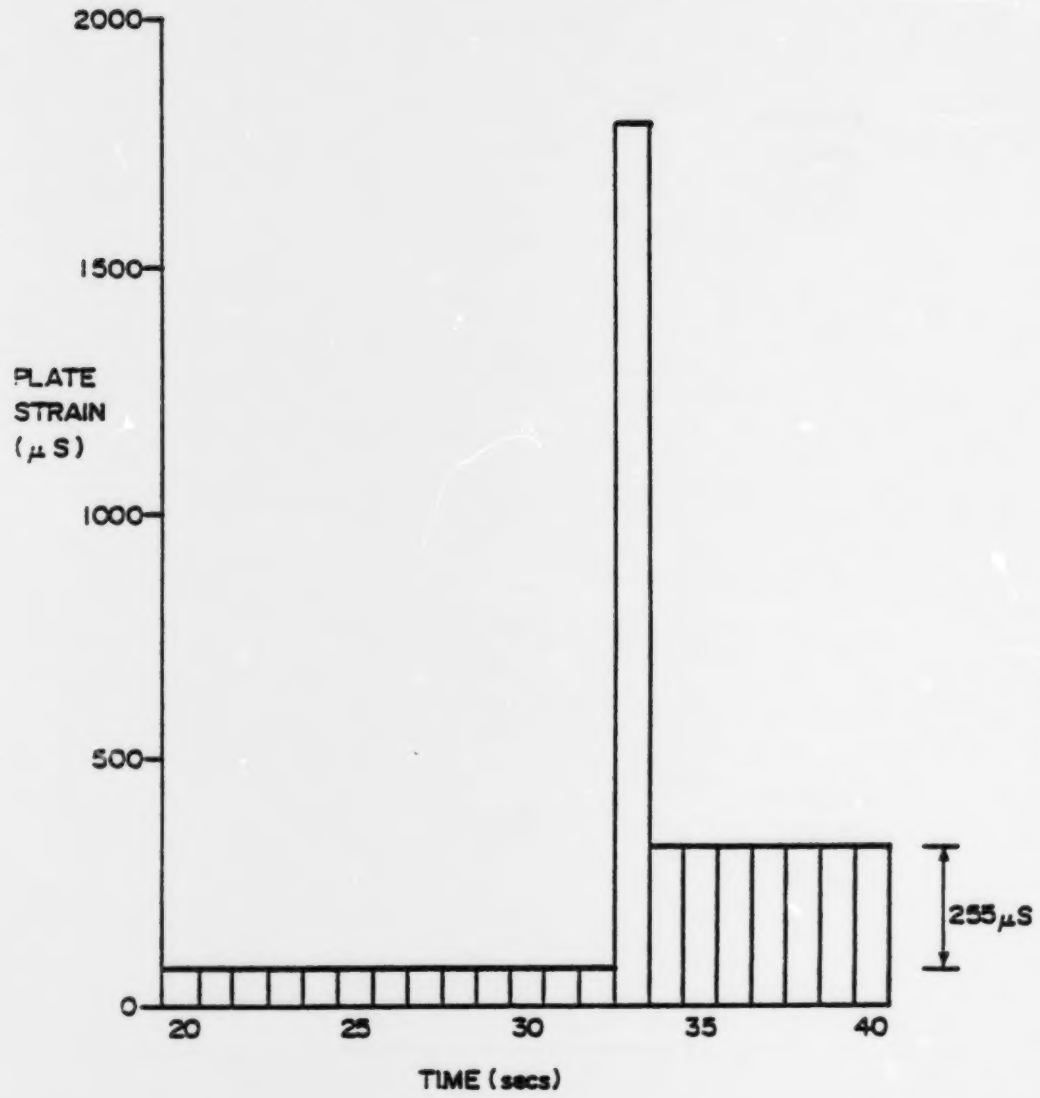
ATTACHMENT 5.9



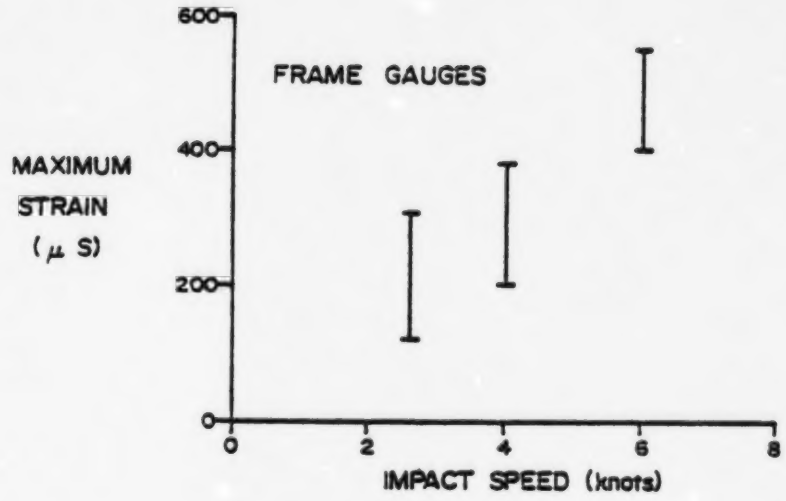



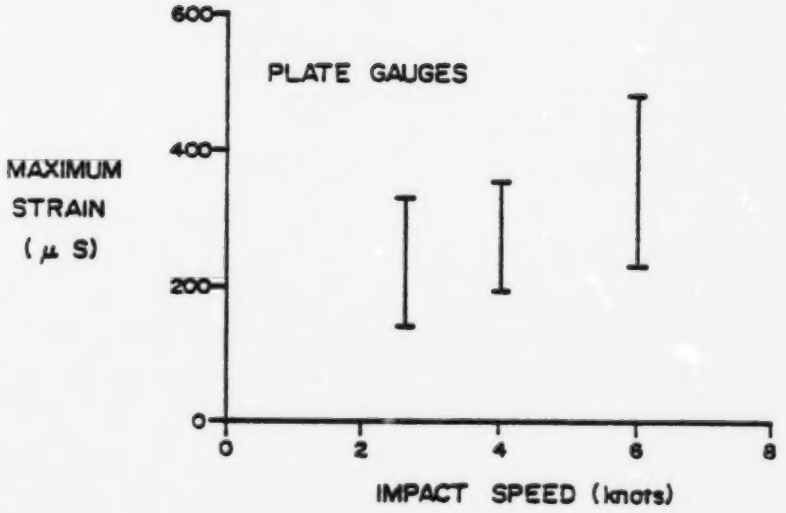

Histogram of frame strain and plate strain occurrence for passage through 1.5 m level ice at 2 knots.
00.30 - 01.00 GMT. 9 July 1981.

ATTACHMENT 5.10




Impact and resultant deformation of plate between frames 184 and 186 and stringers 4 and 4A at 16.29 GMT, 16 July 1981.



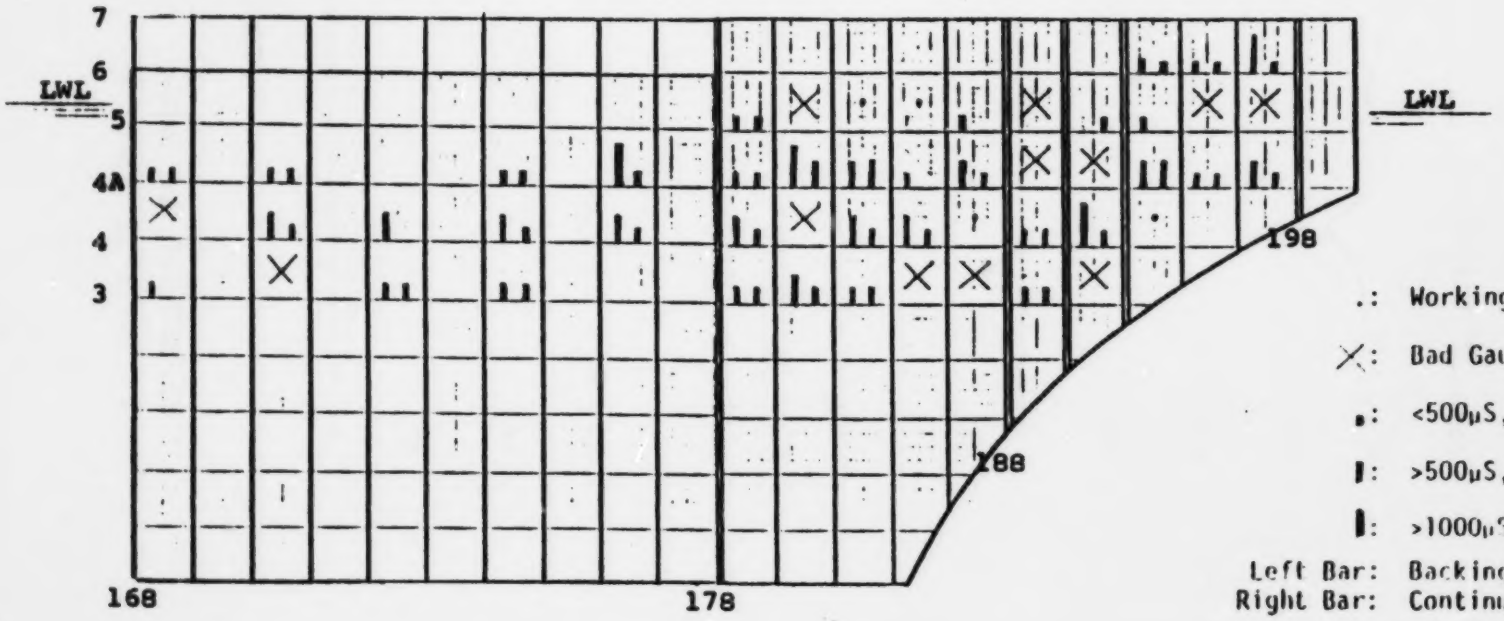




Range of maximum strains recorded during several rams at each of three impact speeds.

## COMPARISON OF RAMMING AND CONTINUOUS MODE FRAME STRAINS

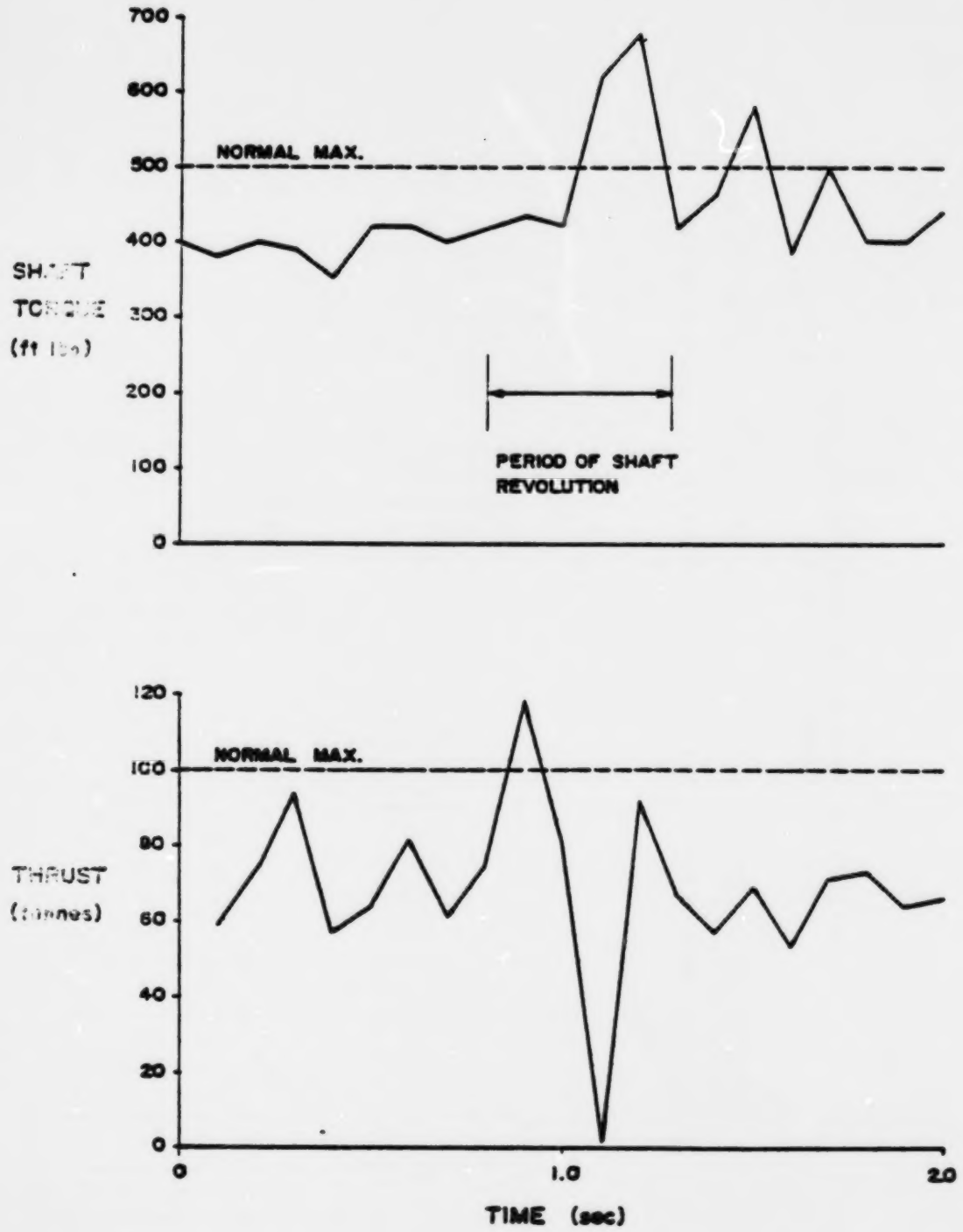
**RAMMING** Nov 12/81 7/10 1st yr, 1/10 2nd yr 2/10 MY in pack

**CONTINUOUS** Nov 8/81 8/10 1st yr, 2/10 MY Speed 8 knots

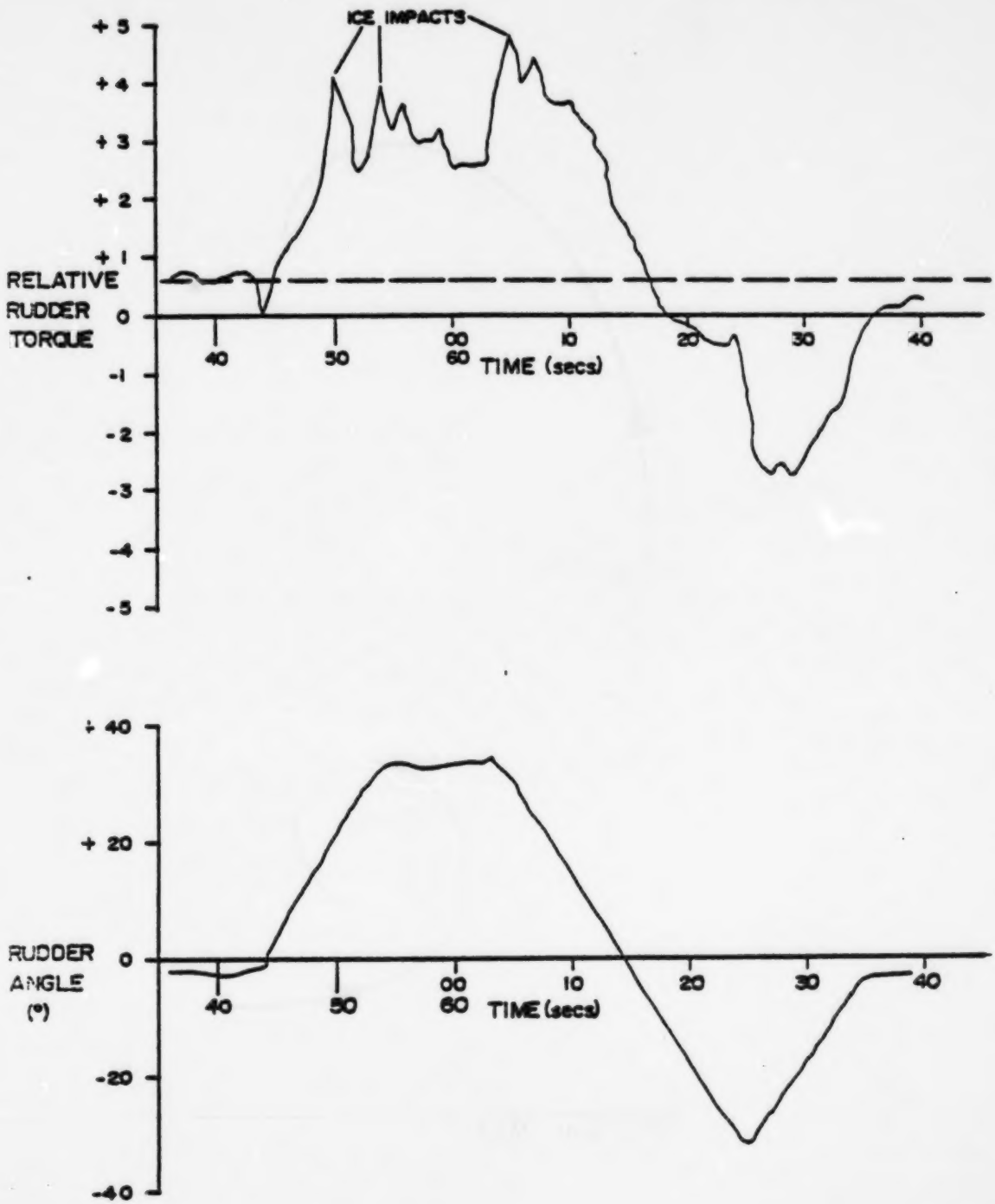



ATTACHMENT 5.12

ATTACHMENT 5.13

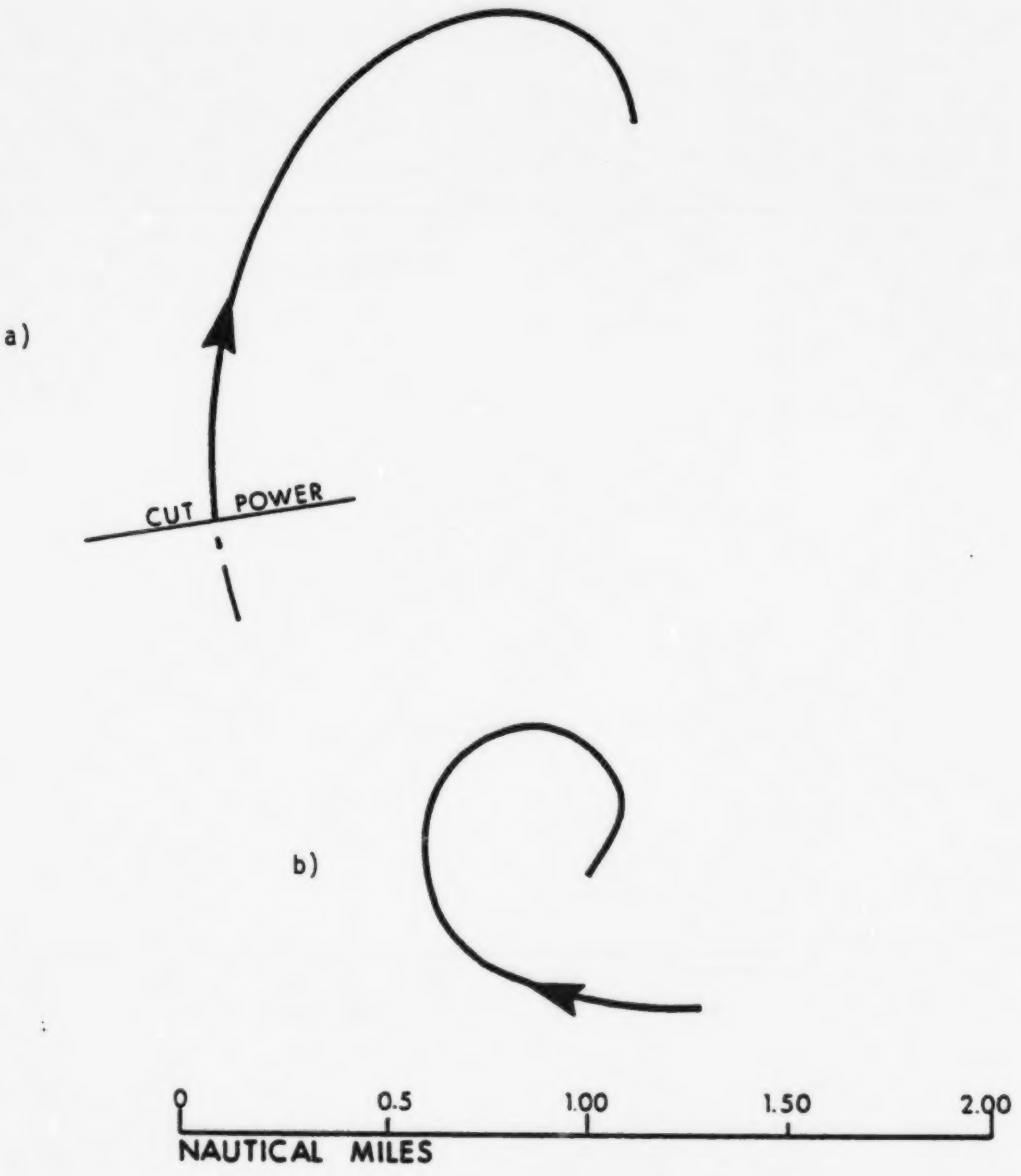



EFFECT OF ICE IMPACT ON THE PROPELLER
AT 14·18·25 GMT, 8th JULY 1981




RUDDER TORQUE AND ANGLE MEASURED FROM 18.23—18.24
7th JULY 1981, SHIP SPEED INCREASING FROM 1 TO 4 KNOTS

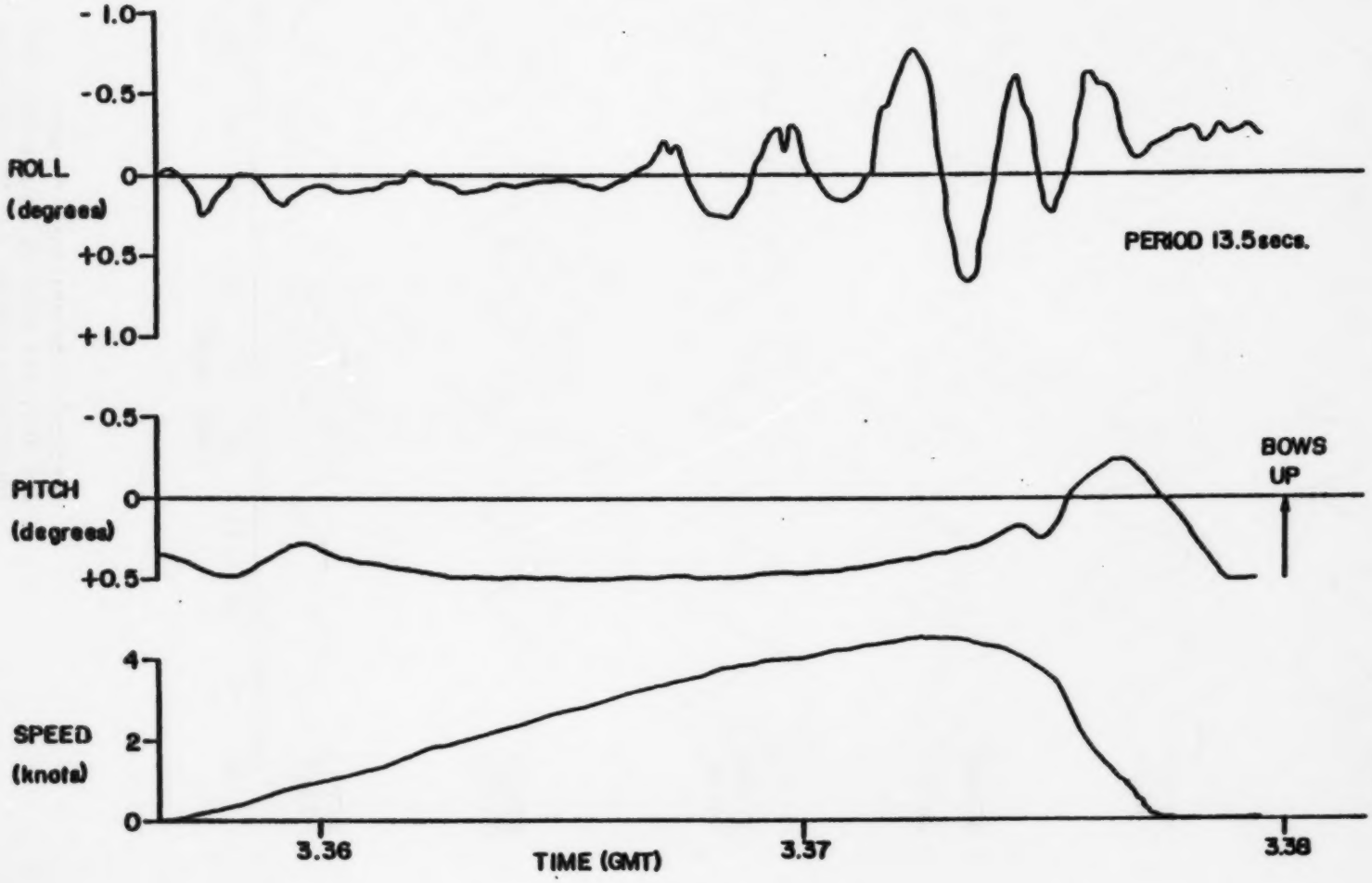
ATTACHMENT 5.1 5




TURNING CIRCLES OF THE M.V. ARCTIC IN 33 cm ICE

a) WITHOUT BUBBLER. SHP = 8000 (METRIC)

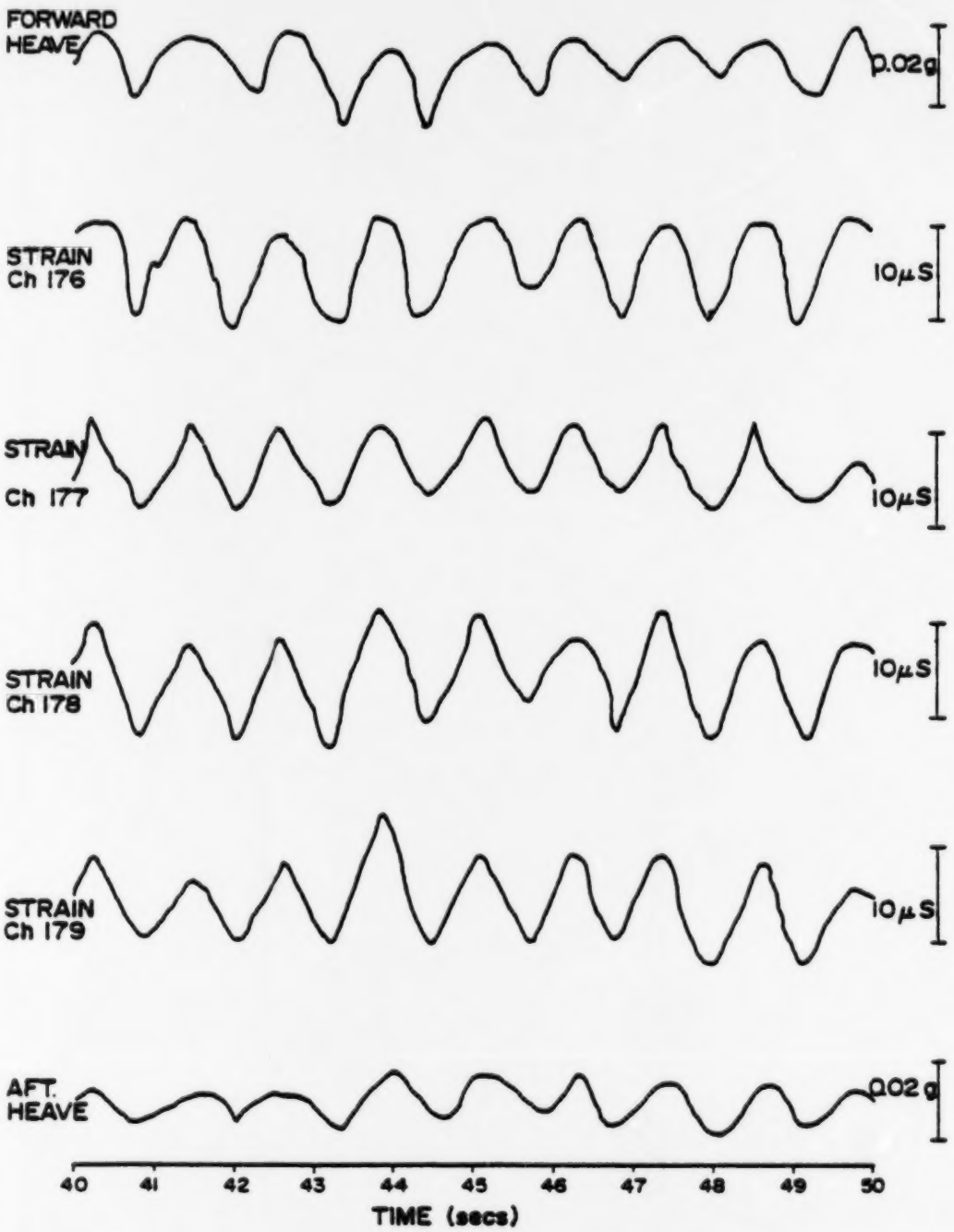
b) WITH BUBBLER, SHP = 8000 (METRIC)




Pitch and roll of the ship when ramming a ridge

ATTACHMENT 5.16

ATTACHMENT 5.17




Vertical accelerations forward and aft, and strains in mid-section longitudinal beams due to the 2-node mode of vertical hull vibration.

# 6. REVIEW OF THE DATABASE

## 6.1 Summary of the database

In the previous sections of this report reviews were made of the Program Objectives, the Instrumentation System and the Data Collection Program. In terms of data analysis, the database acquired over the three arctic seasons and the four dedicated trials provides the means of addressing substantially all the program objectives, particularly as they relate to the CASPPR provisions. This is summarised in Attachment 6.1,.

The depth to which these objectives can be addressed, however, depends upon the comprehensiveness of the database measured in terms of the adequacy of the sampling rates and patterns used in recording the data. A summary of the actual sampling rates applied to the principal sensors is provided in Attachment 6.2 for each season and dedicated trial. In reviewing the adequacy of these sampling rates, it is necessary to use as a yardstick the theoretical sampling rates needed for various analytical purposes.

## 6.2 Sampling principles

The data acquisition system installed on the mv Arctic combines analogue sensors with digital recording of the data. This means that the sensor signal can only be accurately reconstructed from the data records if the signal sampling rate has been properly selected. To that end, a prior knowledge of the signal characteristics to be recorded is needed which will usually fall into one of the following four categories,

1. Regular harmonic or periodic signal shapes such as are produced from sensors fitted to record rotational and oscillatory motions resulting from, propulsion plants, ship motions, accelerations,etc.

2. Irregular, non-harmonic signal shapes such as are produced from sensors fitted to record strains from hull structure, etc.

3. Steady or slow change signal shapes such as are produced from sensors fitted to record ship's course, hull temperature, environmental and related conditions, etc.

4. Combined signal shapes which are composed of a mixture of the above three categories.

In each case, certain sampling principles have to be followed which demand a prior knowledge of the rate of change of the signal shape and other characteristics. The general principles are as follows,

Category 1. Sampling theory requires that the sampling frequency be at least twice the signal frequency to avoid aliasing - see Attachment 6.3. A higher sampling rate is required, however, in order to provide sufficient data points from which to reconstruct the shape of the signal. A minimum sampling rate of five times the signal frequency is needed for simple waveform reconstruction with this multiplier increasing for more complex waveform signals. Accordingly, for real-time recording a minimum of five times the expected signal frequency has to be adopted. Peak recording can be done at twice signal frequency but is only useful if the digital system can differentiate between positive and negative peaks of the signal.

Category 2. There is no waveform frequency to be detected in this case but the signal may be composed of a number of irregularly spaced peaks such as would be recorded from strain gauge signals. The total time duration with the rise and decay shapes of the signal peaks are of interest. If each signal peak is considered to be one cycle, then a minimum of five samples per cycle would be required for real-time recording. In evidence of this, a strain gauge signal for a 0.2 second cycle is compared in Attachment 6.4 when sampled at 500 samples/sec (100 samples/cycle) and at 25 samples/sec (5 samples/cycle). There is little distortion or loss of resolution at the lower sampling rate. Peak recording can be done at one sample per peak-to-peak interval based upon averages.

Category 3. Sampling rates can be chosen according to the expected rate of change of slope of drift signals. Some signals, such as ship's course, will show rapid excursions between long steady-state periods. Thus, the area of interest may change from the average course record to data on the instantaneous ship's heading during a turning circle manoeuver. The sampling rate would have to be adjusted to accommodate the required precision.

Category 4. The sampling rate would depend upon the particular area of interest. A typical example would be the ship's heading which would be sampled under, category 3 for general course information, category 2 for manoeuvering information and category 1 for precise directional stability data.

## 6.3 Database sampling assessment

The above general principles can be applied to some of the more important sensor groups used on the mv Arctic and compared with the actual sampling rates adopted so as to provide a means of assessing the adequacy of the database for various analytical purposes. Four main sensor groups are summarised in the table below and followed by supporting explanation.

| SENSOR GROUP | Object of analysis | Sampling Rate/sec | | Comments on Database |
|---|---|---|---|---|
| | | Object | Actual | |
| STRUCTURAL | Static response | 25 | 10-40 | Adequate 1979 |
| | Dynamic response | 425 | 500 | Adequate 1981 |
| | Strain distrib'n | 1 | 1 | Adequate 80-81 |
| PROPULSION | Ice response | 5 | 10-100 | Adequate 79-81 |
| | System response | 50 | 10-100 | Adeq at high Hz |
| STEERING | Static response | 1 | 1 | Adequate 79-81 |
| | Dynamic response | 5 | 1 | Not adequate |
| MOTIONS | | | | |
| -rotational | Rigid response | 1-5 | 1-10 | Adequate |
| -translation | Rigid response | 1 | 1-50 | Ample |
| -flexing | Dynamic response | 5-20 | 1-50 | Adeq at high Hz |

Structural Group. As stated previously under Category2, strain gauge signal reconstruction requires data to be recorded at a minimum rate of 25 samples per second. This provides information suitable for determining the static response of the Structure (strain rise and decay) to ice impact loads. In the 1979 season, the strain gauges were recorded at between 10 and 40 samples/sec and thus are suitable for static response analysis. In 1980 and 1981 seasons the majority of gauges were recorded at one sample per second peak mode and thus provide a substantial database for strain statistical distribution analysis.

Investigation of structural dynamic response requires much higher sampling rates. Attachment 6.5 shows,for a web frame dynamical response, a primary mode period of 0.012 seconds equivalent to about 85 cycles per second, based upon the finite element model developed for the mv Arctic. Using a sampling multiplier of five under Category 1, a minimum sampling rate of 425 samples/sec would be needed for dynamical analysis. In the 1981 season a few selected gauges were recorded at 100 and 500 samples/sec, thus providing a basis for both statical and dynamical analysis.

Propulsion Group. System induced fluctuations of shaft torque caused by the propellor will occur at a periodic frequency corresponding to the blade passing rate of 145 rpm at 4 blades equal to about 10 cycles per second. Applying a minimum multiplier of five under Category 1, a sampling rate of 50 per second is needed for adequate signal reconstruction for system induced torsional analysis. During the three seasons 1979 to 1981, the predominant sampling rate was 10 samples/sec with a few records taken at 100 samples/sec. Accordingly, dynamic torsional fluctuations can only be partially investigated but the total records will provide a substantial database for the detection of non-periodic torsional excursions due to external causes such as ice ingestion into the propellor. Similar conclusions arise concerning the database for other parameters of the propulsion system such as, shaft thrust, revolutions and blade torque, none of which provide extensive high-frequency records related to system induced fluctuations but give adequate low-frequency records for the detection of ice induced effects.

Steering Group. Rudder command, response and ship's head are all recorded at one sample/sec. This database is only just sufficient to permit a very coarse analysis to be made of the ship's directional stability and hence of rudder efficiency in ice navigation. Whilst the vessel's

period of yaw is probably greater than one second when in ice, a record of about 5 samples/sec would be needed to give sufficient data points for a more accurate investigation of the ship's directional response to the rudder.

Ship Motions Group. Rigid body motions of the ship are recorded from two groups of sensors as follows,

| Group | Type of motion | Motions |
|---|---|---|
| Gyro-sensors | Rotational | Roll, Pitch, Yaw |
| Accelerometers | Translational | Heave, Surge, Sway |

Both sensor groups fall into Category 1, with a minimum sampling rate of five times the motion cycle. The periods of roll and pitch appears to be about 10 seconds - see Attachment 6.6, hence a sampling rate of about one per second is required. Yaw having a shorter period would require a higher sampling rate as referred to previously under the Steering Group. Throughout the data acquisition period, records from the gyro-sensors were taken at rates mainly between 1 and 10 samples/sec.

The second group of sensors are measuring translational motions which, being more inertial, will have longer cycle periods than the rotational motions. Consequently, a sampling rate of one sample/sec is probably adequate for investigation of these three rigid-body translational motions. Actual recordings have been made at rates varying between 1 and 50 samples/sec with a predominant rate of 10 samples/sec and thus are more than adequate for rigid-body analysis. However, the accelerometers are fitted at each end of the vessel and so are also subjected to vibrational and flexing accelerations. These can either be eliminated by the use of low pass filters or captured by use of higher sampling rates. The primary modes of vertical and lateral vibration have frequencies of about 4 and 1 cycles/sec respectively. Capture of these would therefore require records taken at a minimum of 20 and 5 samples/sec respectively, which are also within the above described database.

It can be seen from the foregoing Table and discussion that the acquired database of the mv Arctic program provides adequate records for the determination of the static (ice-induced and rigid-body) response effects. This is a principal objective of the Program and so far as data acquisition is concerned the objective is being achieved.

In addition, certain records will provide a good measure of insight into the dynamic (ice-induced and system induced) response considerations for three of the four main sensor groups under review. This substantially broadens the analysis potential of the database. To that end, the static and where possible the dynamic response considerations have been built into the tasking requirements of the studies to be conducted under the Detailed Data Analysis Program which has now commenced.

## 6.4 Database sampling patterns

The foregoing evaluation of sampling rates provides a measure of the database analysis potential. Whilst it is highly desirable to obtain statical and dynamical response information from the data records, it must be kept in mind that the instrumentation system is limited to a maximum recording capacity of 1765 samples/sec. Accordingly, only limited use can be made of the dynamical recording mode, for example four strain gauges each sampled at 500 samples per second would exceed the total system capacity and leave no room for recording the numerous other sensors.

One possible solution to this problem, without increasing system capacity, would be to rotate the static and dynamic response sampling requirements sequentially among the four main sensor groups. For instance, when ice conditions remain relatively unchanging, a 20 minute recording period could be sub-divided into four 5 minute periods and the recordings made as shown in the following table.

| Sensors | 5 minute periods | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Structural | Dyn | Stat | Stat | Stat |
| Propulsion | Stat | Dyn | Stat | Stat |
| Steering | Stat | Stat | Dyn | Stat |
| Motions | Stat | Stat | Stat | Dyn |

The above strategy was employed to some extent during the 1979 - 1981 data collection period but the recordings were made over much longer time durations which makes the inter-relationship of results from the various sensor groups more difficult. A further problem which arose was the failure of many sensors making sampling patterns difficult to maintain. Strain gauges, shaft revs and shaft torque have been notable problem areas and where possible reliance has had to be placed on manual records. Nevertheless, all indications are that an adequate database has been collected which will yield quantitative and qualitative results related to the program objectives.

## STATUS WITH RESPECT TO PROGRAM OBJECTIVES

ATTACHMENT 6.1

| Program Objectives | Detailed Analysis Potential | Type of Database Required | Extent of Database Available |
|---|---|---|---|
| **1. Evaluation of CASPPR Design Criteria** | | | |
| *Schedule F - Structural Standards* | | | |
| - Hull strength areas | ✓ | Structural strain gauge records for ice impacts and loads in various ice regimes at various ship speeds | 3 years arctic navigation seasons (bow area only) |
| - Shell thickness | ✓ | | |
| - Frame strength | ✓ | | |
| - Web strength | ✓ | | |
| - Stringer strength | ✓ | | |
| *Schedule F - Rudder & Steering Gear* | | | |
| - Strength criteria | ✓ | Hydraulic ram differential pressure, rudder stock strain and torque, rudder command and response in various ice conditions and ship speeds | 3 years arctic navigation scans and Kempf manoeuvers |
| - Power requirements | ✓ | | |
| *Schedule F - Subdivision and Stability* | x | — | — |
| *Schedule G - Machinery Requirements* | | | |
| - Powering formula (ahead/astern) | ✓ | Power, speed and structural response in various ice regimes | 4 dedicated trials |
| - Ice torque factor (Prop/Shaft/Gear) | ✓ | Power, Revs, Pitch against torque and thrust spectra in various ice conditions and various ship speeds | 4 dedicated trials and 3 arctic seasons |
| - Propeller blade (Strength/Thickness) | ✓ | | |
| - Propeller submergence | ✓ | | |
| - Shaft diameter | ✓ | | |
| - Cooling water inlets | x | Engine Room Logs on cooling temp & flow | 3 years data |
| - Air starting system | ✓ | — | — |
| **2. Evaluation of CASPPR Seasonal Criteria** | | | |
| - Navigation Zones (Class II) | ✓ | Geographical data on ship performance and ice conditions | 3 arctic seasons |
| - Navigation Seasons (Class II) | ✓ | Temporal data on ship performance and ice conditions | |
| **3. Development of New Navigation Equipment** | | | |
| - Evaluate instrumentation system | ✓ | System operators reports & maintenance records | 3 years/4 operators |
| - Provide criteria for other systems | ✓ | Comprehensive data on ship performance and ice conditions | 3 full seasons |
| - Develop other equipment | ✓ | Comprehensive data on ship performance and ice conditions | 3 full seasons |
| **4. Determine Ship Performance and Model Correlation** | | | |
| - Icebreaking performance | ✓ | Speed/power data in various ice regimes | 4 dedicated trials plus arctic voyages |
| - Resistance Prediction | ✓ | Full scale/model scale ice speed - power | |
| - Manoeuvering performance | ✓ | Turning, backing and docking data in ice | |
| - Ship motions (rigid body) | ✓ | Gyro and accelerometer data in various ice regimes | 3 arctic seasons |
| - Propulsive performance | ✓ | Thrust, torque and speed in various ice regimes | |
| **5. Evaluate Auxiliary Systems** | | | |
| - Bubbler system | ✓ | Ship speed and power in ice with/without Bubbler | 4 dedicated trials |
| - Hull coating | x | — | — |
| - Propeller duct | ✓ | Propeller thrust in ice compared with open-water performance | 3 arctic seasons and trials |
| **6. Advance Knowledge of Arctic Marine Operations** | | | |
| - Icebreaking tactics | ✓ | Energy optimisation of icebreaking performance | From objective 4 |
| - Manoeuvering tactics | ✓ | Energy optimisation of manoeuvering performance | From objective 4 |
| - Construction principles | ✓ | Optimisation of shell, frame and stringer strengths | From objective 1 |
| - Inspection strategies | ✓ | Structural impact, stress and temperature data | 3 arctic seasons |

ATTACHMENT 6.2

## SENSOR SAMPLING RATES

Samples/second
P = peak R = real

| SENSORS | SEASONS | | | | TRIALS | | | |
|---|---|---|---|---|---|---|---|---|
| | 1979 | 1980 | 1981E | 1981L | SAG | BAF | MEL | ADM |
| STRUCTURE | | | | | | | | |
| Stbd bow - Plates | 10R-40R | 1P | 1P-500R | 1P-100R | 1P-40R | 1P-100R | 1P-100R | 1P-100R |
| - Frames | 10R-40R | 1P | 1P-500R | 1P-100R | 1P-40R | 1P-100R | 1P-100R | 1P-100R |
| - Webs | 10R-40R | 1P | 1P | 1P | 10P-40R | 1P | 1P-100R | 1P |
| - Strngrs | 10R-40R | 1P | - | - | 40R | 1P | 1P-10R | - |
| Port bow - Plates | 10R-40R | 1P | - | 1P | 40R | 1P-100R | 1P-10R | - |
| - Frames | 10R-40R | 1P | - | 1P | 40R | 1P-100R | 1P-10R | - |
| Midships - Plates | - | 1P | 50R | 1P-100R | - | 1P | - | 1P |
| - Frames | - | 1P | 50R | 1P-100R | - | 1P | - | 1P |
| Inner Skin (Stbd) | 1R-40R | 1P | - | - | 40R | 1P | 1P-10R | - |
| PROPULSION | | | | | | | | |
| - Fuel rack | 1/10R | 10R | 10R | 1R | 1/10R | 10R | 1R | 10R |
| - Ens RPM | 1R | - | - | - | - | - | - | - |
| - Shaft RPM | - | - | 1R | 10R | - | - | 1R-100R | 1R |
| - Shaft Torque | 1R-10R | - | 10R | 10R-100R | - | - | 1R | 10R |
| - Thrust | 1R-1R | 10R | 10R | 10R-100R | 1R | 10R | 1R | 10R |
| - Pitch command | 1R | - | - | 1R | 1R | - | 1R | - |
| - Pitch response | - | - | - | - | - | - | - | - |
| - Prop diff press | 1R-10R | - | - | 1R | - | - | - | - |
| STEERING | | | | | | | | |
| - Rudder command | 1R | - | - | 1R | 1R | - | 1R | - |
| - Rudder response | 1R | 1R | 1R | 1R | 1R | 1R | 1R | 1R |
| - Rudder torque | - | - | 1R | 1R | - | - | - | 1R |
| - Bubbler press | 1/10R | - | - | - | 1/10R | - | - | - |
| - Bubbler valve | 1/10R | - | - | - | 1/10R | - | - | - |
| MOTIONS | | | | | | | | |
| - Accelerometers | 1R-10P | 1P | 1P-50R | 1P-50P | 10P | 1P | 10P | 1P-50R |
| - Pitch, Roll | 1/10R-1R | - | 10R | 10R | 1/10R | - | 1R | 10R |
| - Compass | 1R | 1R | 1R | 1R | 1R | 1R | 1R | 1R |
| - Speed | 1/10R | 1R | 1R | 1R-10R | 1/10R | 1R | 1R | 1R |

**ATTACHMENT 6.3**

## SIGNAL ALIASING

### Source

Van Nostrand's Scientific Encyclopedia

5th Ed

**ALIASING ERROR** (Data Acquisition System). Shannon's sampling theorem states that in order to reconstruct a signal containing frequency components in the spectrum 0 to $f_m$ Hz from sampled data, uniformly spaced samples must be taken at a rate of at least $2f_m$ samples per second. Failure to obtain data at this rate converts high-frequency components into low-frequency components. Thus, the reconstructed signal contains low-frequency energy not present in the original signal. Figure 1 illustrates a 5-Hz signal sampled at a 4-samples-per-second rate. The reconstructed signal has a frequency of 1 Hz. An *aliasing error* is an error which can be introduced into sampled data in a digital-data-acquisition system as the result of violation of the basic sampling theorem.

The term *aliasing* results from the interpretation that the high-frequency components take the "alias" of a lower-frequency component. An equivalent term *folding error* arises from the interpretation that the frequency spectrum of the signal is folded such that high-frequency components appear in a lower-frequency spectrum.

Sampling a continuous signal is equivalent to modulating the signal with a series of uniformly spaced impulses as indicated in Fig. 2. If a signal containing frequency components up to a frequency $f_m$ is modulated by a carrier of frequency $f_s$, the frequency spectrum of the resulting sampled signal consists of the original spectrum, plus harmonic spectra centered on the sampling frequency and its harmonics as shown in Fig. 1. This is the same effect as the modulation of an rf carrier with an audio signal in amplitude-modulated radio, except that there are an infinite number of carrier frequencies because the frequency spectrum of a train of equally spaced impulses (the modulating signal) consists of an infinite number of frequency components at $f_s$ and its harmonics.

Figure 1 shows that if the sampling frequency $f_s$ is less than $2f_m$, the lower sideband of the first-harmonic spectrum overlaps the original signal spectrum. Inasmuch as mathematical signal-reconstruction methods are equivalent to low-pass filtering in the signal domain, it is evident that the signal energy from the first-harmonic spectrum which overlaps the original spectrum will be passed by the low-pass filter and, therefore, will affect the nature of the reconstructed signal.

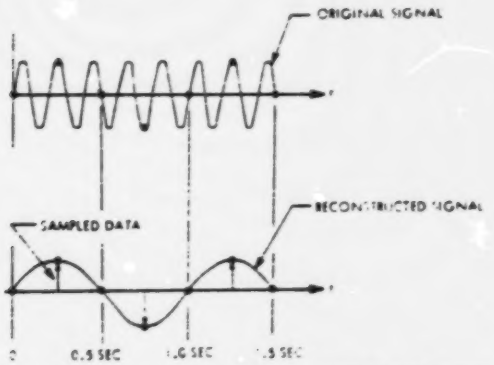
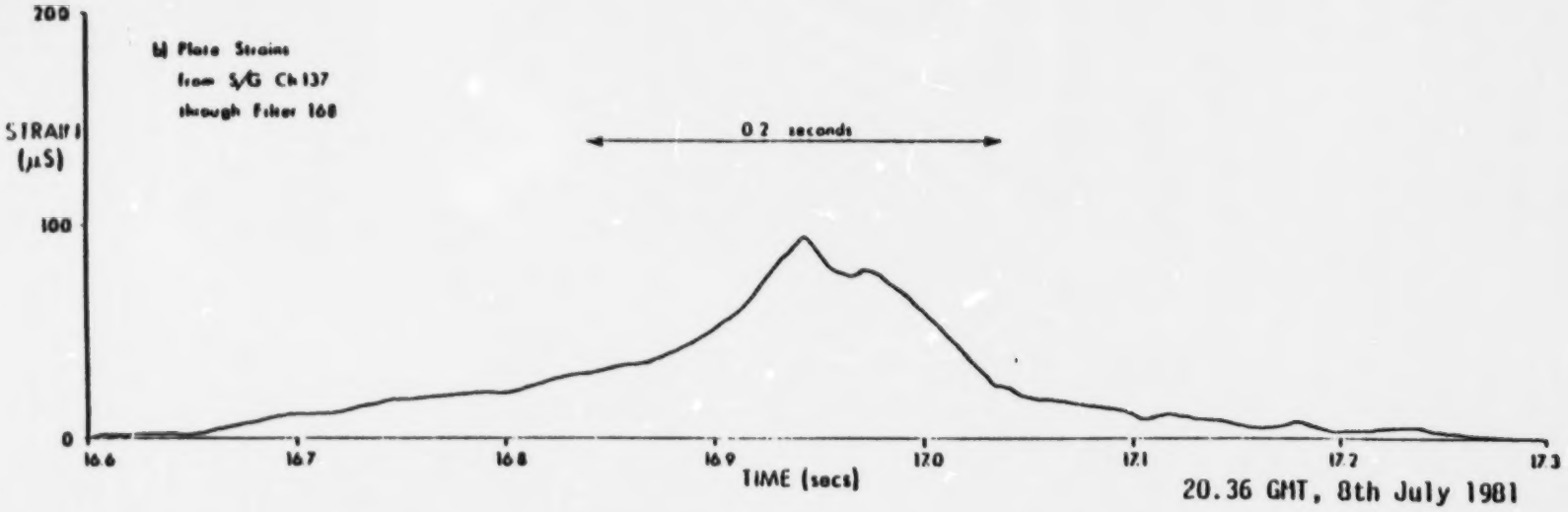


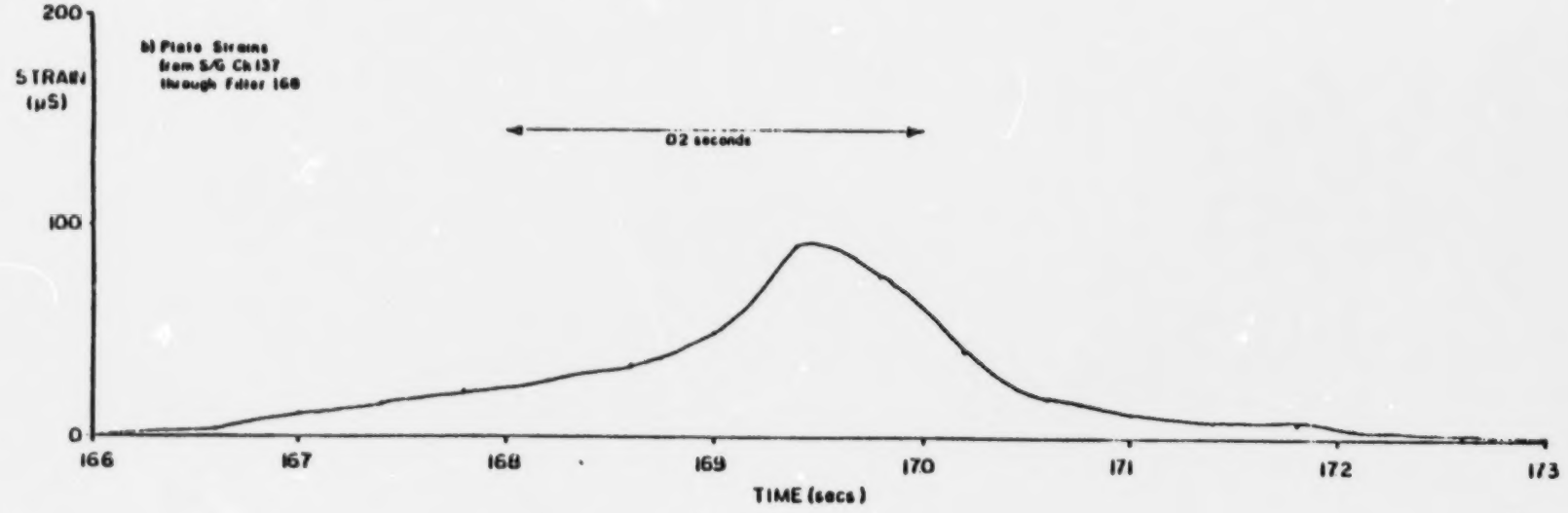

Fig. 1. Example of aliasing error in a sampled-data system.

In the foregoing description, the signal was assumed to have no frequency components above the frequency $f_m$. In practice, signals are not definitively band-limited and high-frequency components are present in any real signal. In the majority of process-control applications, the signals are nominally band-limited by the low-pass characteristics of the process or the signal transducers. In connection with such signals, the sampling theorem frequently is stated so as to require sampling at twice the highest *significant* signal frequency. In practice, selection of the sampling frequency depends upon the interpretation of the term significant. A rule of thumb is that the sampling rate should be 5 to 10 times the highest frequency of interest. Although not technically perfect, the rule is valuable inasmuch as signals are usually band-limited to reject frequencies above those of interest. The 5 or 10 multiplier provides a safety factor to account for the finite rolloff rate of most low-pass systems. Where accurate reconstruction of the sampled signal is needed, an estimate of the aliasing error should be made.



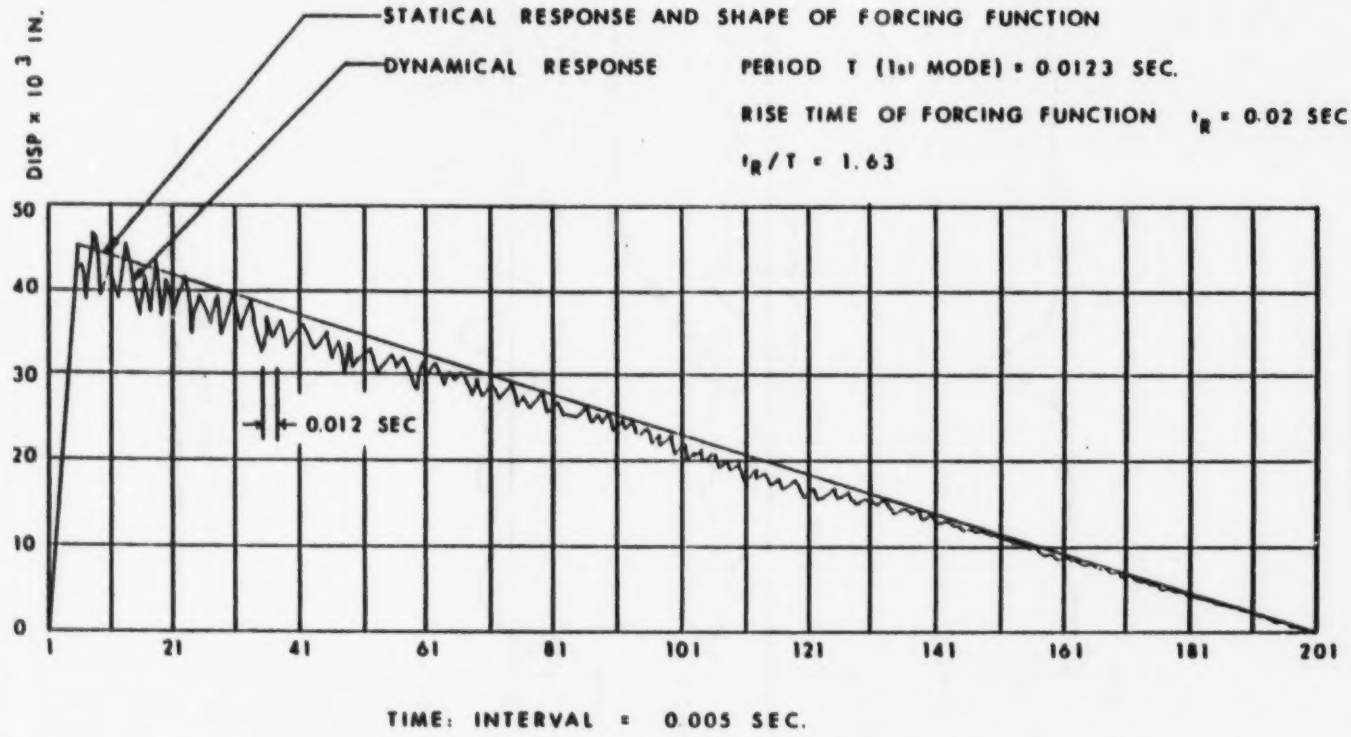

20.36 GMT, 8th July 1981

Impact at 4.4 knots, ramming first-year ice recorded at 500 samples/sec.




ATTACHMENT 6.4

Impact at 4.4 knots, ramming first-year ice recorded at 25 samples/sec.

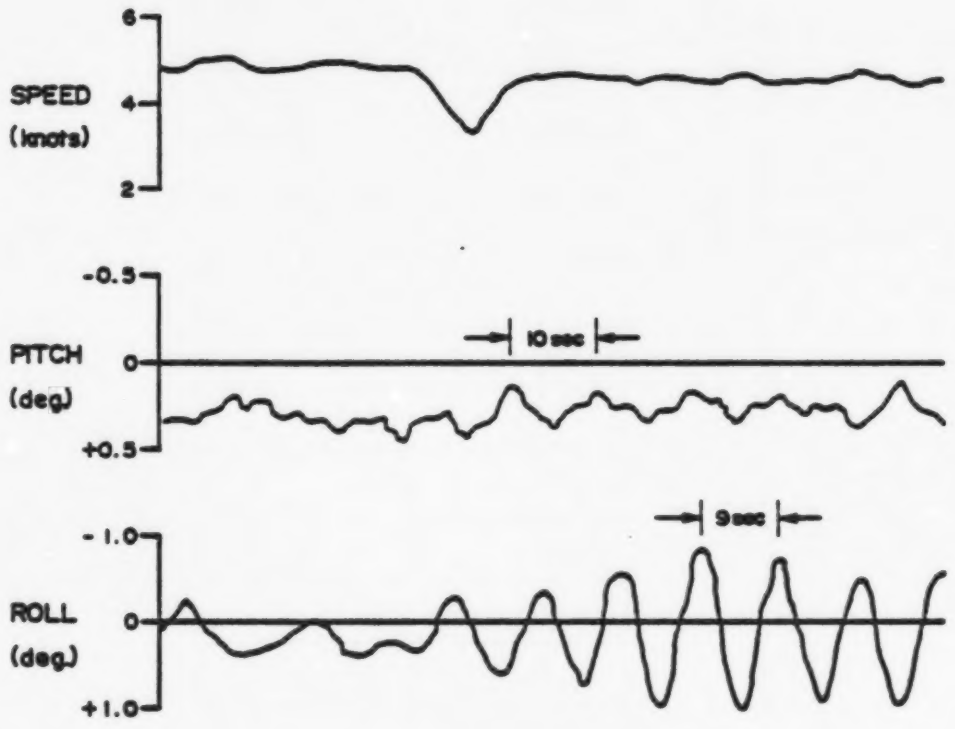



ATTACHMENT 6.5

DYNAMICAL RESPONSE - NODE 37- DOF 1

ATTACHMENT 6.6

## ROLL & PITCH




Roll of the ship during
ice impacts above the waterline.

## 7. PLAN OF DETAILED DATA ANALYSIS

An overall strategy for the detailed data analysis activity was developed in 1982 and the Master Plan for this is given in Attachment 7.1,. It was immediately evident that the various analyses could not be performed until the databank and supporting records gathered during the acquisition phase had been assembled into a readily useable form and identified for the purposes for which they would be used. A major element of that identification process was to cross reference ice data with sensor information and the vessel's transiting mode ( continuous, ramming, manoeuvering, etc ). A further major element was to prepare a comprehensive chronology of sensor history throughout the acquisition phase so as to facilitate the validation of the raw data recorded on each tape. Accordingly, the first step towards implementation of the Master Plan was to prepare a Master Data Package which addressed all these subjects and which was completed by German & Milne Inc in December 1982. In parallel with this an Ice Load Determination methodology was developed by Fenco Consultants Ltd for converting the recorded strain data into ice loads and pressures on the shell of the ship.

The Master Plan,referred to above,identified six main projects utilising inputs from the voyage monitoring and dedicated trials databanks as the bases for the analyses and interpretations. In a subsequent refinement of the plan, the number of analysis projects was reduced from six to five by incorporating ship motions into the others where appropriate. There was a special purpose in planning for a multi-project approach, namely, to ensure that each performance category; icetransiting, structure, propulsion, manoeuvering, would be addressed by experts in each field thereby ensuring the most searching evaluation in each subject. This was preffered to a single project approach which would likely result in some aspects being well addressed whilst others would only receive superficial treatment. The multi-project approach also has the virtue of involving a wider spectrum of Canadian marine expertise which is an underlying objective of the mv Arctic program.

Data analysis will necessitate a highly statistical approach and,thus,the Master Plan also allows for an independent overview if required to validate the various statistical methods adopted by the performers of the five main projects.

The Master Schedule for these five main projects is given in Attachment 7.2 and the program was put into effect in January 1983 through the issuance of a series of requests for proposals through the Department of Supply & Services. The position reached at the end of July 1983, the date of this interim report, is as follows;

Ice-Trans (cont) - Contracted to Albery, Pullerits, Dickson & Assocs May 1983

Ice-Trans ( ram) - Contract under negotiation July 1983

Propulsion - Contracted to Melville Shipping Ltd June 1983

Manoeuvering - RFP issued for bids

Structural (a) - Bids received and under evaluation

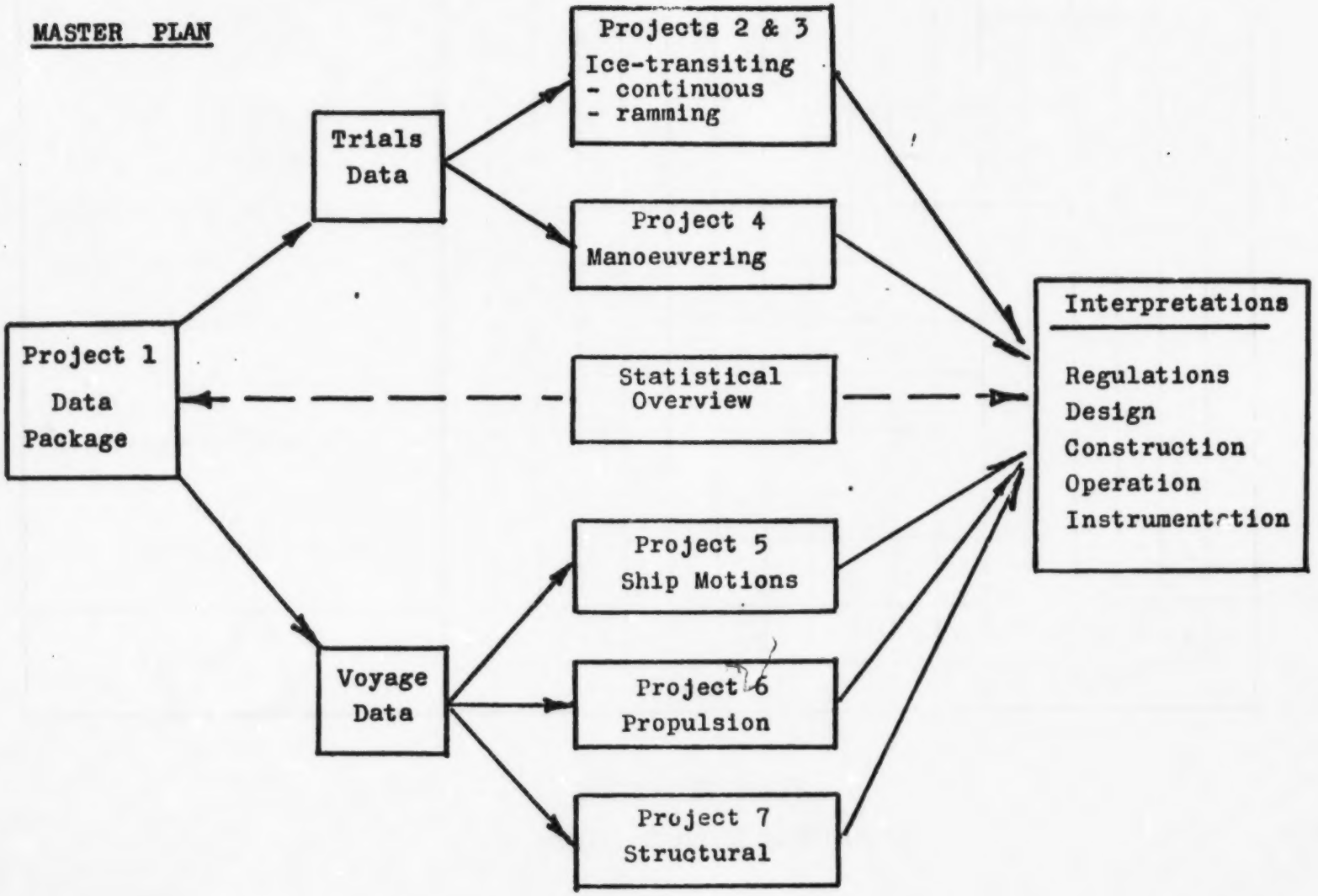
The Structural Performance project is composed of a main project and two sub-projects, the latter being conditional upon the progress and results obtained from the former. The intention is that once a clear picture of the ice loading and strain patterns and spectra are adequately identified, then further investigations into structural design optimisation and the probable fatigue life of the structure can be pursued.

The various project objectives are provided in Attachment 7.3, and the Task Descriptions for the five main projects are given as Attachments 7.4 to 7.8,. In each case it will be noted that there are three facets to the work requirement, namely,

- Depth analysis and interpretation of the database
- Critique of the data acquisition system and strategy.
- Identification of more advanced analytical opportunities.

All of the above will provide a basis for evaluating the case for the development of new instrumentation systems which is one of the specific objectives of the mv Arctic scientific program. The reports of the above projects will also set down their findings in a way which will address the particular interests of regulators, designers, builders amd operators of arctic ships. Thereafter, these results will be brought together in a Summary Report planned for mid 1984 completion.

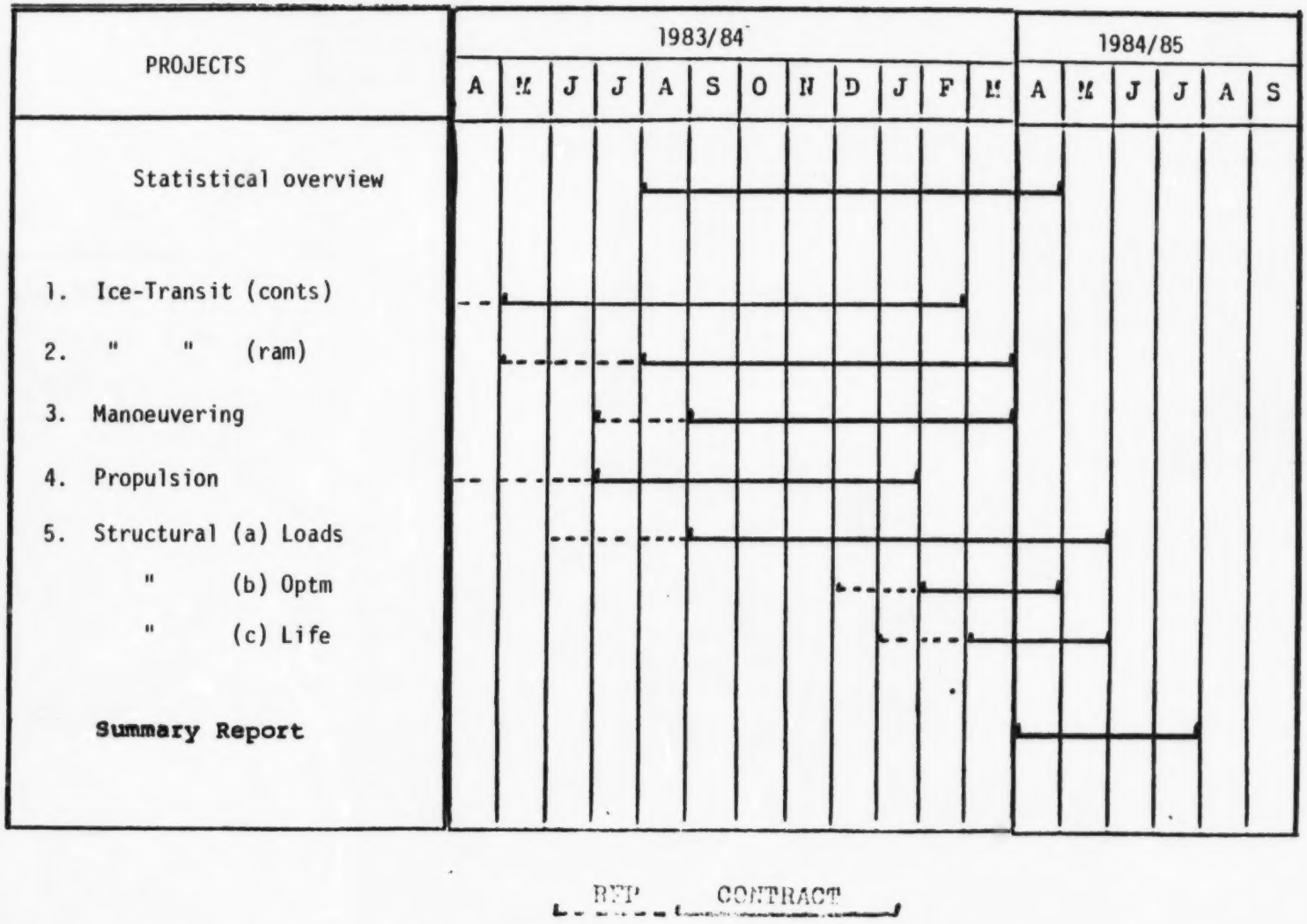
**MASTER PLAN**




ATTACHMENT 7.1

mv ARCTIC - DETAILED DATA ANALYSIS

MASTER SCHEDULE




ATTACHMENT 7.2

mv ARCTIC

DETAILED DATA ANALYSIS

| ANALYSIS GROUP | PROJECT GROUP | OBJECTIVES |
|---|---|---|
| **Overview** | Statistics | To validate the statistical methods used in the following data analysis projects |
| Operational | Icebreaking Performance (continuous mode) | To develop ice, speed, power and resistance equations for continuous mode icebreaking in level ice and broken channels |
| | Icebreaking Performance (ramming mode) | To establish the ramming mode and ridge penetration capabilities of the mv Arctic and identify the optimum ramming tactics |
| | Manoeuvering Performance | To determine turning circle, directional stability and docking characteristics of the mv Arctic |
| | Ship Motions | To obtain equations for rigid body motions covering pitch, roll, heave, surge and yaw |
| | Propulsive Performance | To determine the thrust and torque spectra resulting from ice ingestion and the effect on strength and performance criteria for the main machinery, gear train and propellers |
| | Structural Performance | To examine hull-ice structural inter-relationships in the following three connections:<br>a) Ice loading and distribution<br>b) Structural design optimisation<br>c) Structural life expectancy |

ATTACHMENT 7.3

# M.V. ARCTIC - ICE TRANSITING PERFORMANCE

## (CONTINUOUS MODE)

## STATEMENT OF TASKS

The project will consist of the following 15 main tasks:

1 Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures within one month of effective commencement date.

2 Identify and review the various continuous mode (level ice, partial ice and broken channel etc.) resistance formulations which have been developed in Russia, Europe and North America. Evaluate for dependence on ship and ice parameters and select for suitability of application to ice-capable cargo vessels such as the M.V. Arctic with step-by-step logic supporting the choice.

3 Scan the M.V. Arctic 1979-1981 databank of voyage monitoring and dedicated trials records. Sub-divide into clearly defined data categories which span the range of analyses to be undertaken into the vessel's ice-transiting continuous mode performance. These categories shall take into account such independent variables as ice conditions, power and speed, draft and trim, bubbler status etc. and should be agreed with TDC.

4 Extract from the records, validate, tabulate and reduce the ship and ice data to be used in the various ice-transiting (continuous mode) performance analyses corresponding to the above agreed categories.

5 Develop appropriate ahead (and astern) continuous mode ice-transiting performance formulations for the M.V. Arctic corresponding to the above agreed categories. Those formulations shall take into account the findings of Task 4.2 and the recommendations of the ITTC Committee on ships in ice-covered Waters.

6 Prepare graphical and other visual methods of clearly describing the M.V. Arctic's continuous mode ice-transiting capability corresponding to the agreed performance analysis categories. Use the results as best to interpolate and extrapolate to vessels of lower and higher ice class. All such performance relationships shall ignore any considerations of structural strength.

7 Evaluate the minimum ahead and astern power provisions of schedule G of CASPPR in terms of the vessel's continuous mode ice-transiting capabilities. Determine the techno-economic significance of the "as fitted" power level, which should include consideration of any optimum energy-related power settings for continuous mode ice-breaking.

8 Compare and evaluate the model scale data against the full scale results of the continuous mode ice-transiting performance corresponding to the agreed performance categories. Those comparisons and the resulting correlations should be based on the existing data base and shall not be dependent on additional model tests.

9 Evaluate the main features of the M.V. Arctic hull form geometry directly and against known state-of-the-art variations in terms of their respective contributions to the vessel's continuous mode ice-transiting performance ahead and astern in various ice conditions.

10 Evaluate the techno-economic significance of the bubbler system on the M.V. Arctic's continuous mode ice-transiting performance.

11 Evaluate the rigid body motions (heave, surge, sway, yaw, pitch and roll) under the various conditions of continuous mode ice-transiting performance. Develop appropriate equations of motion in respect of the six degrees of freedom.

12 Evaluate the instrumentation system, sampling patterns, acquisition strategies and acquired databank of the 1979-1981 program period with particular reference to their effect on the objective of comprehensive performance evaluation of the vessel's continuous mode ice-transiting capabilities.

13 Propose supplementary areas of evaluation of the vessel's continuous mode ice-transiting performance not directly addressed by the foregoing tasks but available from the existing data base. Permission to proceed with such supplementary evaluation tasks will be conditional upon TDC prior approval.

14 Assemble in report form, the data, analyses, findings, conclusions and recommendations arising from the foregoing continuous mode ice-transiting performance study. Best use should be made of visual aids; diagrams, graphs, photos etc. to support the findings and conclusions of the subject matter. The form of the report should carefully separate and address the respective needs of (i) designers and (ii) operators of ice classed commercial vessels.

15 Provide progress, interim draft and final documents to TDC as described in Section 8.

# M.V. ARCTIC - ICE TRANSITING PERFORMANCE

## (RAMMING MODE)

## STATEMENT OF TASKS

The project will consist of the following 15 main tasks:

1 Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures within one month of effective commencement date.

2 Identify and review the various ramming mode (level ice, broken ice, ridges, etc.) resistance/progression formulations which have been postulated in Russia, Europe and North America. Evaluate for comprehensiveness of ship and ice parameters and select for suitability of application to ice-capable cargo vessels such as the M.V. Arctic with step-by-step logic supporting the choice.

3 Scan the M.V. Arctic 1979-1981 databank of voyage monitoring and dedicated trials records. Sub-divide into clearly defined data categories which span the range of analyses to be undertaken into the vessel's ice-transiting ramming mode performance. These categories shall take into account such independent variables as ice conditions, power and speed, draft and trim, bubbler status, etc. and should be agreed with TDC.

4 Extract from the records, validate, tabulate and reduce the ship and ice data to be used in the various ice-transiting (ramming mode) performance analyses corresponding to the above agreed categories. A particular objective of this data reduction process will be to develop dimensional and strength algorithms for the classification of ridges.

5 Develop appropriate ramming mode ice-transiting performance formulations for the M.V. Arctic corresponding to the above agreed categories. These formulations shall take into account the findings of Task 4.2 and the recommendations of the ITTC Committee on Ships in Ice-covered Waters.

6 Prepare graphical and other visual methods of clearly describing the M.V. Arctic's ramming mode ice-transiting capability corresponding to the agreed performance analysis categories. Use the results, as best, to define the transition zone between continuous and ramming modes, the apparent maximum ramming mode capability in level and broken ice, and to identify the maximum significant ridge which the vessel can just penetrate without being stopped. The results should also be used to interpolate and extrapolate to vessels of lower and higher ice class. All such ramming performance relationships shall ignore any considerations of structural strength.

7 Evaluate the minimum ahead and astern power provisions of Schedule G of CASPPR in terms of the vessel's ramming mode ice-transiting capabilities. Determine the techno-economic significance of the "as fitted" power level and, in association with Task 4.6, identify the optimum energy related tactics for ramming mode ice-breaking.

8 Evaluate the techno-economic significance of the bubbler system on the M.V. Arctic's ramming mode ice-transiting performance.

9 Utilise the findings of the foregoing evaluations of the M.V. Arctic's ramming mode capabilities to determine the extent and probabilities of any ice-transiting delays/restraints which the vessel might expect to experience in zones 13 and 6 during her permitted entry periods as set out in Schedule H of CASPPR. This task shall ignore considerations of structural strength.

10 Evaluate the main features of the M.V. Arctic hull form geometry etc. directly and against known state-of-the-art variations in terms of their respective contributions to the vessel's ramming mode ice-transiting performance in various ice conditions. This should include evaluation of ice milling in the astern mode.

11 Evaluate the rigid body motions (heave, surge, sway, yaw, pitch and roll) under the various conditions of ramming mode ice-transiting performance. Develop appropriate equations of motion/acceleration in respect of the six degrees of freedom.

12 Evaluate the instrumentation system, sampling patterns, acquisition strategies and acquired databank of the 1979-81 program period with particular reference to their effect on the objective of comprehensive performance evaluation of the vessel's ramming mode ice-transiting capabilities.

13 Propose supplementary areas of evaluation of the vessel's ramming mode ice-transiting performance not directly addressed by the foregoing tasks but available from the existing database. Permission to proceed with such supplementary evaluation tasks will be conditional upon TDC prior approval.

14 Assemble in report form, the data, analyses, findings, conclusions and recommendations arising from the foregoing ramming mode ice-transiting performances study. Best use should be made of visual aids; diagrams, graphs, photos etc. to support the findings and conclusions of the subject matter. The form of the report should carefully separate and address the respective needs of (i) designers and (ii) operators of ice classed commercial vessels.

15 Provide progress, interim draft and final documents to TDC and attend meetings at TDC as described in Section 8.

## M.V. ARCTIC - MANOEUVERING PERFORMANCE

## STATEMENT OF TASKS

The project will consist of the following 13 main tasks.

1 Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures within one month of effective commencement date.

2 Scan the M.V. Arctic 1979-1981 data bank of voyage monitoring and dedicated trials records. Sub-divide into clearly defined data categories which adequately span the range of analysis to be undertaken on manoeuvering performance. Those categories shall take into account such independent variables as ice conditions, speed, power level, draft, trim, heel, rudder angle, bubbler status etc, and should be agreed with TDC.

3 Extract from the records, validate, tabulate and reduce the ship and ice data to be used in the various manoeuvering performance analyses corresponding to the above agreed categories.

4 Determine the vessel's turning circle characteristics in various ice conditions, rudder angles and power levels etc.. corresponding to the above agreed categories.

5 Determine the amplitude and frequencies of the normal and ice-induced load and torque spectra on the rudder and rudder stock for various ship speed, ice conditions, rudder angle etc... Use the results to evaluate the ice design provisions of Schedule F of CASPPR for rudder and steering gear strengths, operating loads and protection.

6 Develop the command/response characteristics of the steering system relative to change of heading and to directional stability in various ice conditions. Use the results to evaluate the rudder efficiency and the provisions of Schedule F of CASPPR with respect to steering gear operating speed.

7 Evaluate the techno-economic significance of the bubbler system on the M.V. Arctic's manoeuvering performance. Compare this result with the probable techno-economic effect on this vessel's manoeuvering performance of substituting a thruster for the bubbler having (i) the same installed cost and (ii) the same installed power.

8 Evaluate the combined effect of rudder, propeller and nozzle on the swinging and docking in ice characteristics of the vessel. Identify any differences which would result in those characteristics on this service and also under Tasks 4.4 and 4.6 arising form LH or RH propeller.

9 Evaluate the rigid body motions (heave, surge, sway, yaw, pitch and roll) under the various conditions of manoeuvering performance. Develop appropriate equations of acceleration/motion in respect of the six degrees of freedom.

10 Evaluate the instrumentation system, sampling patterns, acquisition strategies and acquired databank of the 1979-81 program period with particular reference to their effect on the objective of comprehensive evaluation of the vessel's manoeuvering performance.

11 Propose supplementary areas of evaluation of the vessel's manoeuvering performance not directly addressed by the foregoing tasks but available from the existing data base. Permission to proceed with such supplementary evaluation tasks will be contitional upon TDC prior approval.

12 Assemble in report form, the data, analyses, findings, conclusions and recommendations arising from the foregoing manoeuvering performance study. Best use should be made of visual aids: diagrams, graphs, photos etc.. to support the findings and conclusions of the subject matter. The form of the report should carefully seperate and address the respective needs of (i) designers and (ii) operators of ice classed commercial vessels.

13 Provide progress, interim draft and final documents to TDC and attend meetings at TDC as described in Section 8.

# M.V. ARCTIC - PROPULSIVE PERFORMANCE

## STATEMENT OF TASKS

The project will consist of the following 12 main tasks:

1 Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures within one month of effective commencement date.

2 Scan the M.V. Arctic 1979-1981 databank of voyage monitoring and dedicated trials records. Sub-divide into clearly defined data categories which adequately span the range of analyses to be undertaken on the propulsion system. These categories shall take into account such independent variables as ice conditions, speed, power level, pitch setting, propeller submergence etc. and should be agreed with TDC.

3 Extract from the records, validate, tabulate and reduce the ship and ice data to be used in the various propulsion system performance analyses corresponding to the above agreed categories.

4 Determine the amplitude and frequencies of normal and ice-induced thrust and torque spectra corresponding to the above agreed categories. Use the results to evaluate the ice design provisions of Schedule G of CASPPR for shaft and gearing strengths and machinery protection.

5 Develop thrust, torque and efficiency curves for the propeller in ice and compare with the corresponding open water and manufacturer's model/standard curves.

6 Determine the effect of ice ingestion into the propeller disc particularly with respect to propeller thrust, blade torque, direction and speed of rotation. Use the results to evaluate the provisions of Schedule G of CASPPR regarding the scantlings and strength of the propeller blades, boss and internal mechanisms and the propeller submergence.

7 Evaluate the techno-economic significance of the additional thrust and protection obtained from the propeller nozzle corresponding to the above agreed performance categories.

8 Develop the command/response characteristics of the main propulsion system relative to the various operating conditions corresponding to the above agreed performance categories.

9 Evaluate the instrumentation system, sampling patterns, acquisition strategies and acquired databank of the 1979-1981 program period with particular reference to their effect on the objective of comprehensive performance evaluation of the vessel's propulsion system.

10 Propose supplementary areas of evaluation of the propulsion system performance not directly addressed by the foregoing tasks but available from the existing data base. Permission to proceed with such supplementary evaluation tasks will be conditional upon TDC prior approval.

11 Assemble in report form, the data, analyses, findings, conclusions and recommendations arising from the foregoing propulsion system performance study. Best use should be made of visual aids; diagrams, graphs, photos, analogue transcripts etc. to support the findings and conclusions of the subject matter. The form of the report should carefully separate and address the respective needs of (i) designers, and (ii) operators, of ice classed commercial vessels and their propulsion systems.

12 Provide progress, interim draft and final documents to TDC and attend meetings at TDC as described in Section 8.

## M.V. ARCTIC - STRUCTURAL PERFORMANCE

## STATEMENT OF TASKS

The project will consist of the following 15 main tasks:

1 Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures within one month of effective commencement date.

2 Scan the M.V. Arctic 1979-1981 databank of voyage monitoring and dedicated trials records. Sub-divide into clearly defined data categories which adequately span the range of analyses to be undertaken on structural performance. These categories shall take into account such independent variables as ice conditions, ship load conditions, power and speed, time of year, etc. and should be agreed with TDC.

3 Extract from the records, validate, tabulate and reduce the ship and ice data to be used in the various structural performance analyses corresponding to the above agreed categories.

4 Determine the total ice load, load and pressure distribution over the instrumented sections of the ship corresponding to the above agreed categories. These calculations should also examine the differential load on either side of the bow. This task will require use of an approved ice load determination methodology capable of handling strain gauge data recorded at sampling rates varying from one to five hundred samples per second. (One such methodology exists and will be made available to the contractor for evaluation).

5 Determine the ice failure characteristics associated with each structural performance analysis category.

6 Determine load and strain spectra (amplitudes, frequencies and histograms) corresponding to the above agreed analysis categories.

7 Determine strain durations and rates for the principal structural members corresponding to the above agreed analysis categories.

8 Identify the conditions under which the recorded structural yields or failures occurred.

9 Apply the principal ice load patterns determine in Task 4.4 to the existing FEM load-strain software program and determine the strain/stress patterns over the instrumented structure. Compare the actual and calculated strains to determine the confidence level in ice load determination. Examine the critical stress concentrations.

10 Evaluate, using the results of this study, the provisions of Schedule F of CASPPR with respect to the extent of the bow area and the specified ice pressure for a Class II vessel. Interpolate and extrapolate as best to other ice classes.

11 Evaluate, using the results of this study, the provisions of Schedule F of CASPPR with respect to the thickness of the shell plating and the section modulus of the main transverse framing of a Class II vessel in general and also as it is applied to the particular structural arrangement forward of Frame 168 on the M.V. Arctic.

12 Evaluate the instrumentation system, sampling patterns, acquisition strategies and acquired databank of the 1979-81 program period and the FEM discretization, software and strain gauge locations with particular reference to their effect on the objective of comprehensive evaluation of the vessel's structural performance.

13 Propose supplementary areas of evaluation of the vessel's structural performance not directly addressed by the foregoing tasks but available from the existing database. Permission to proceed with such supplementary evaluation tasks will be conditional upon TDC prior approval.

14 Assemble in report form, the data, analyses, findings, conclusions and recommendations arising from the foregoing structural performances study. Best use should be made of visual aids; diagrams, graphs, analogue transcripts, photos, etc. to support the findings and conclusions of the subject matter. The form of the report should carefully separate and address the respective needs of (i) designers and (ii) operators of ice classed commercial vessels.

15 Provide progress, interim draft and final documents to TDC and attend meetings at TDC as described in Section 8.

POOR

QUALITY

ORIGINAL